SPECIAL COLLECTOR'S ISSUE

Discover

OCTOBER 2000

TWENTIETH
ANNIVERSARY
ISSUE

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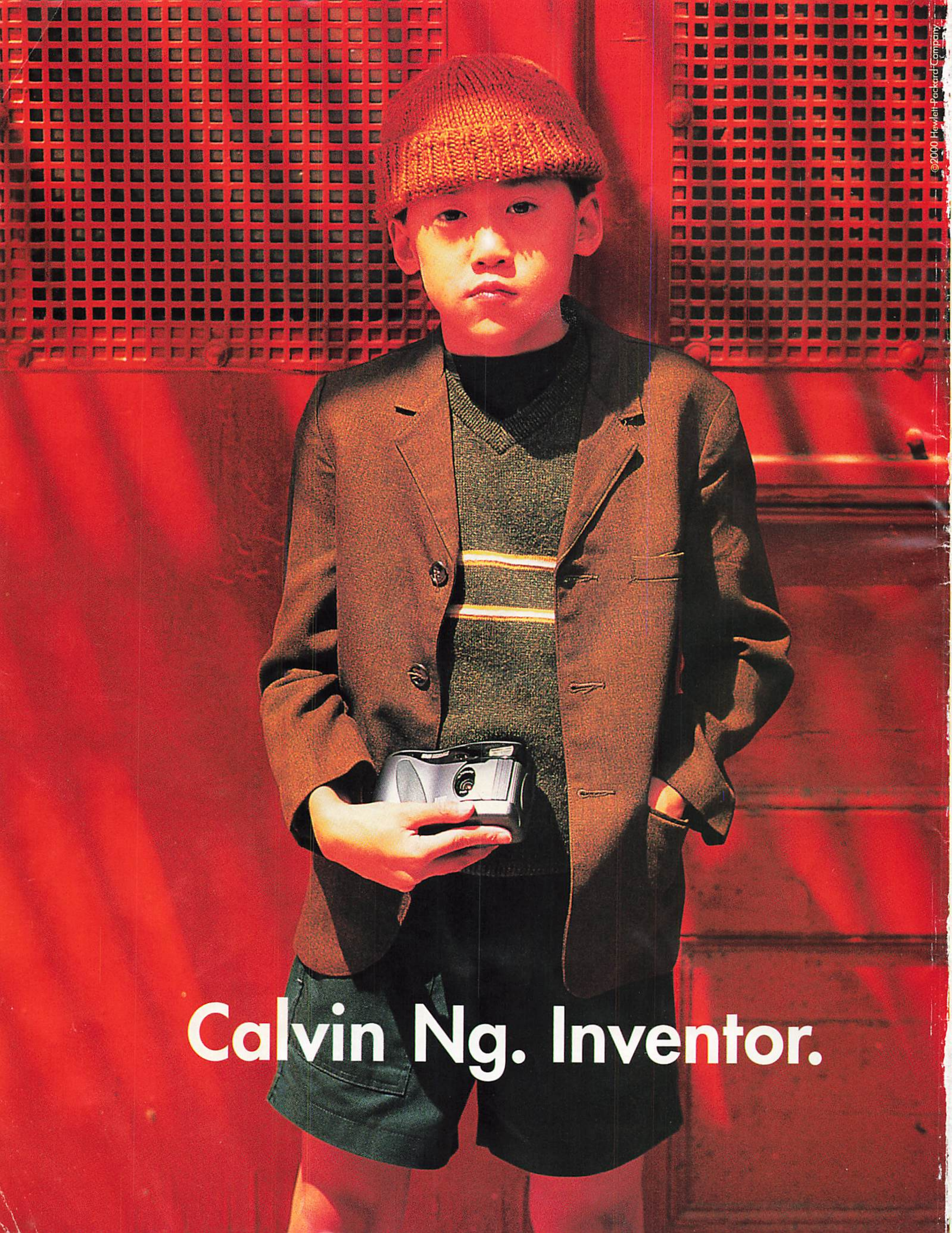
Calvin Ng. Inventor.

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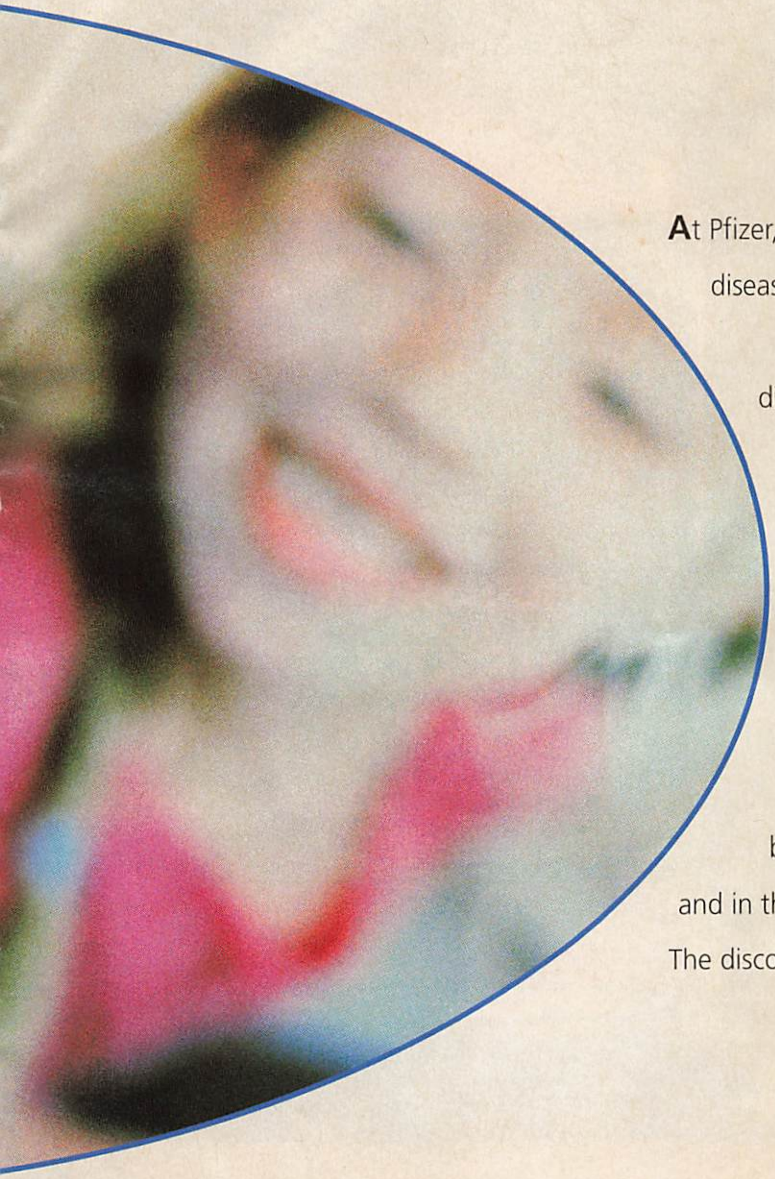

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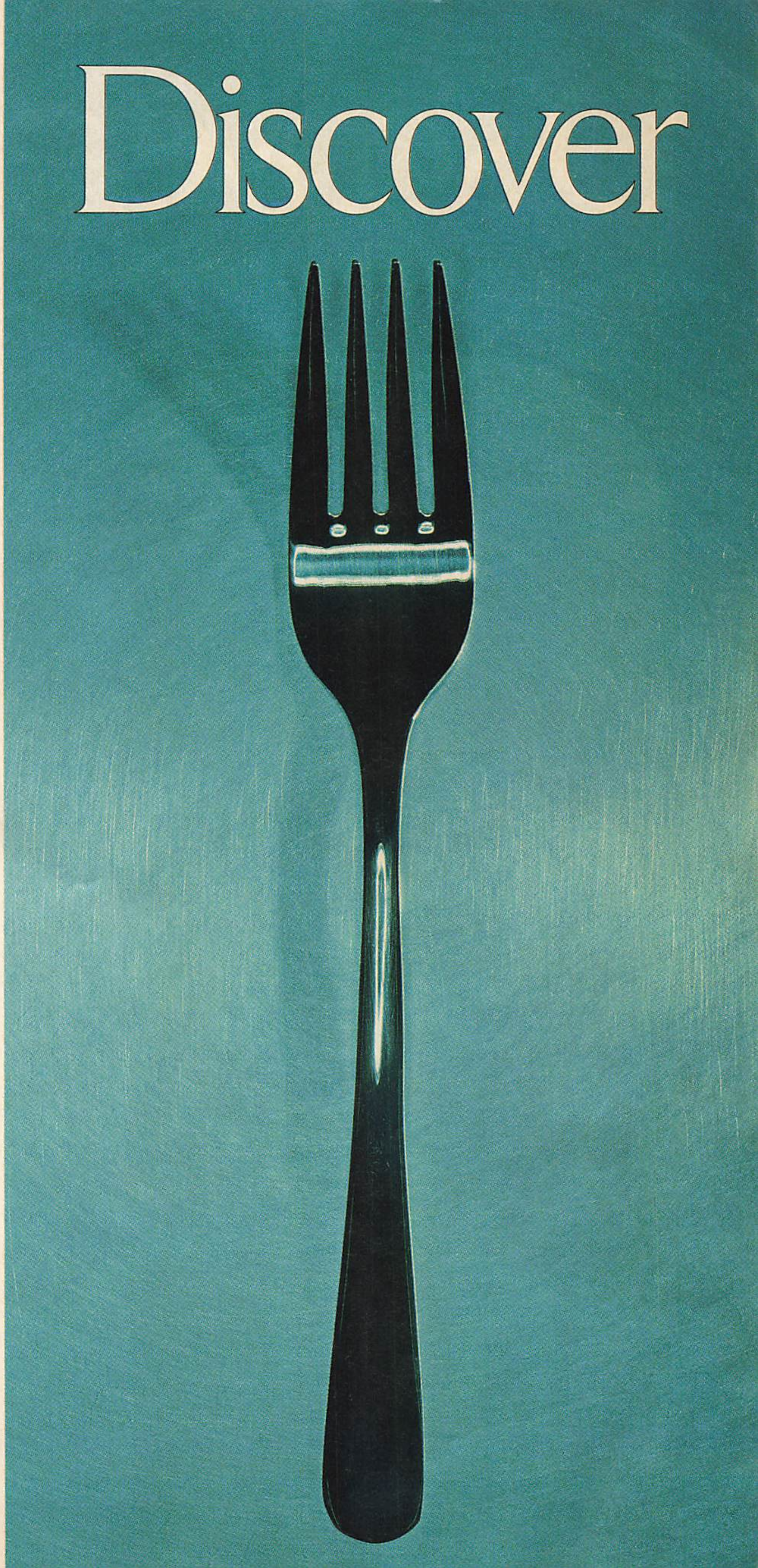

RIGHT: THE FORK WILL ALWAYS BE WITH US; SEE "20 THINGS THAT WON'T CHANGE," PAGE 92.

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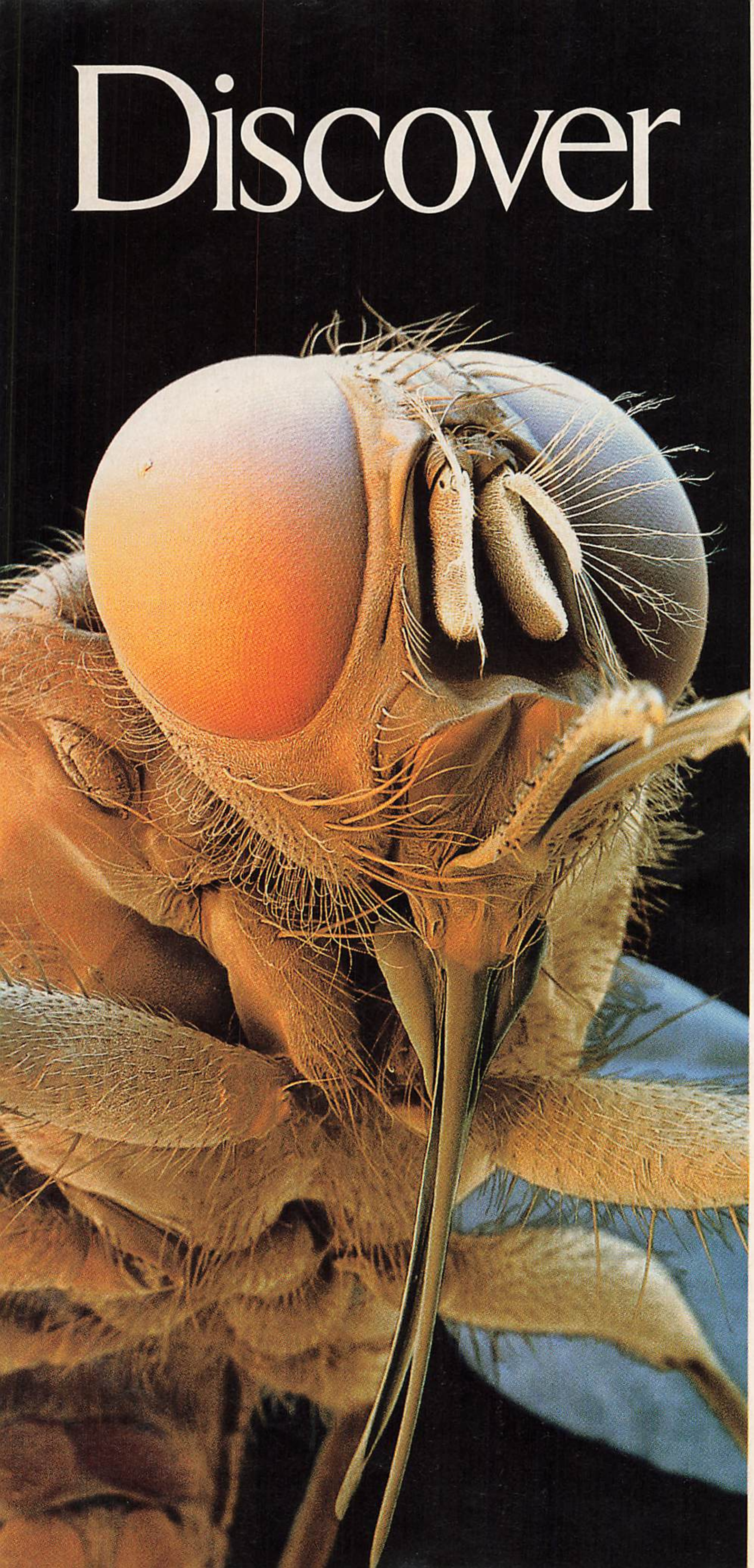

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LEFT: THE TSETSE FLY HARBORS THE PARASITE *TRYPANOSOMA BRUCEI*, WHICH CAUSES SLEEPING SICKNESS; SEE VITAL SIGNS, PAGE 38.

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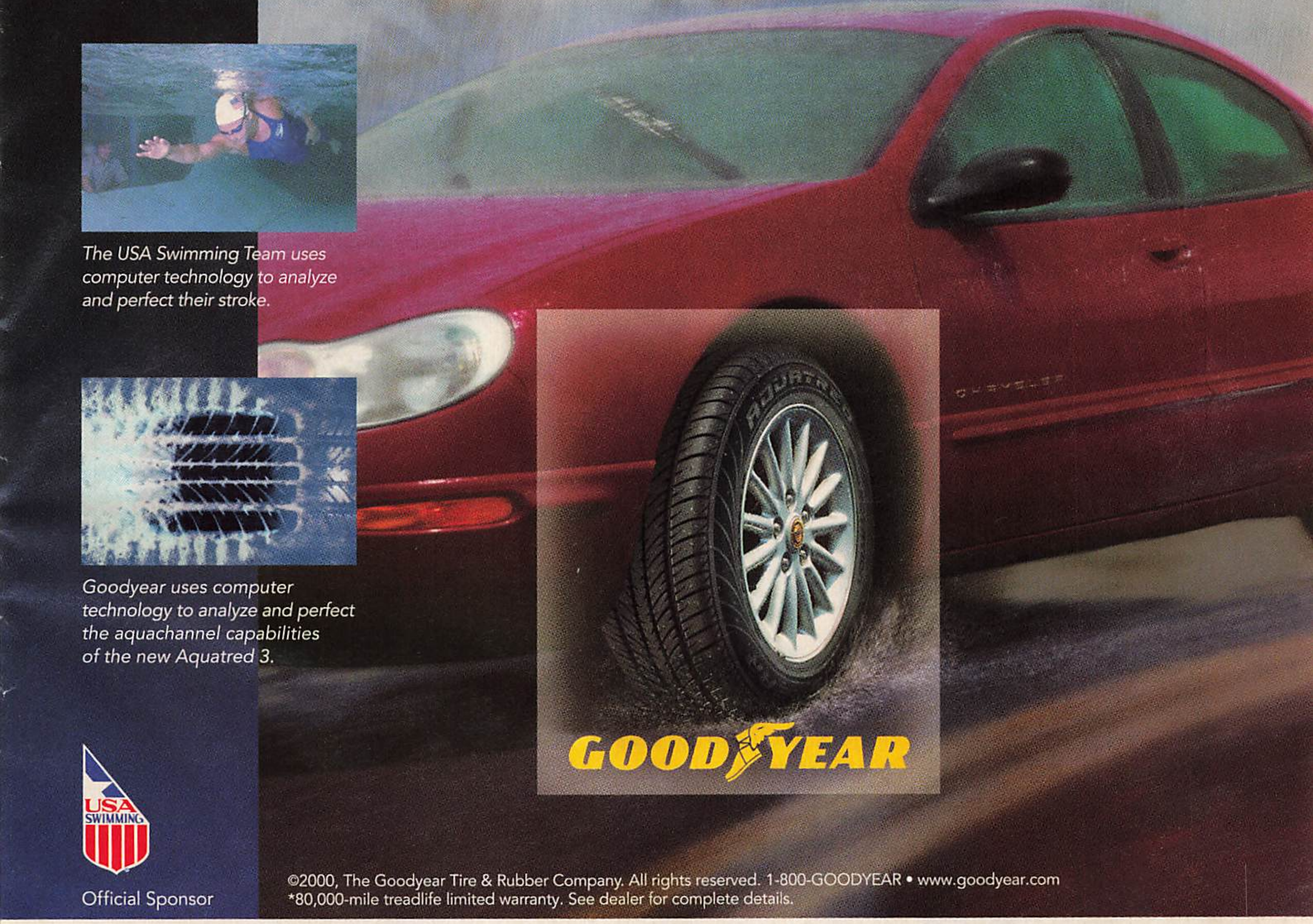
Introducing the all-new Goodyear Aquatred 3.



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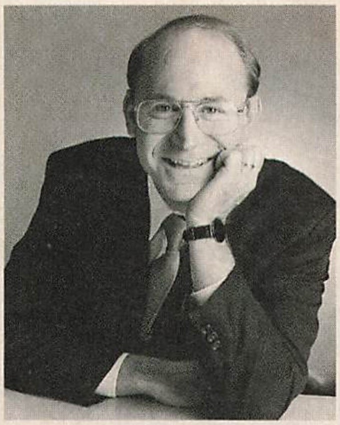
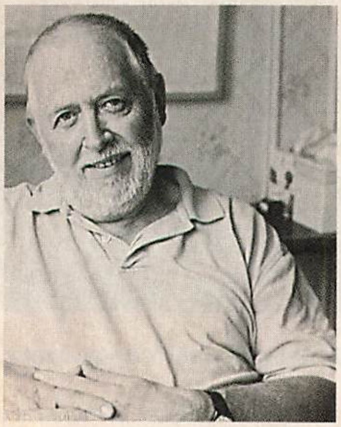


‹ ERIC HASELTINE Growing up in the 1950s in the Mojave Desert, where his father worked as a rocket scientist, Haseltine says he and his three siblings "were bred to be scientists. We lived and breathed science and technology." This parental strategy was successful: Two kids became eminent molecular biologists; one is a computer programmer; and Eric heads Disney's R&D team, where he spends a lot of time envisioning—and creating—the future ("Twenty Things That Will Be Obsolete in Twenty Years," page 84). He also creates Brainworks each month (page 111) and is at work on a book by the same name.

› MARK SINCELL After working as an astrophysicist for six years, Sincell decided he didn't have the "intellectual patience" for benchwork, so he took up the challenge of writing about science instead. The stories that grab his imagination are those of visionary researchers like Bill Ditto (Future Tech, page 28). "Science is often done step by step, but occasionally you come across someone who is incredibly smart and willing to leap into the unknown," says Sincell. He has written for *Physics World* and *Astronomy,* as well as *Earth and Sky,* heard on NPR.



‹ BRUCE McCALL Forever fascinated by automobiles, McCall worked for 25 years as a copywriter in car advertising, writing satire on the side, until seven years ago when he quit to write and illustrate full-time ("Biocrops," page 74). He modestly dismisses his success as an illustrator: "I'd always thought of myself as a writer who happened to have this parlor trick." Last year he had his first one-man New York show at the James Goodman Gallery, and his work now appears regularly in *The New Yorker*, *Vanity Fair*, and *Outside*. He lives in New York City, drives everywhere, and swears he can always find a parking space.

› ROSS MacDONALD Although he denies being a Luddite, MacDonald takes pleasure in wielding the weapon of wit to hold technology at bay ("What You'll Need to Know in Twenty Years That You Don't Know Now," page 58). Until recently he didn't even own a computer. But he finally caved in and bought one for his 5-year-old so the boy would not fall hopelessly out of contention in the modern world. "I think of it as I think of a backhoe," he says. "I could learn to use it, but I'd rather hire someone else to do it." He has done illustrations for *Rolling Stone*, *The New Yorker,* and *Newsweek* and drawn graphics for *Saturday Night Live.*

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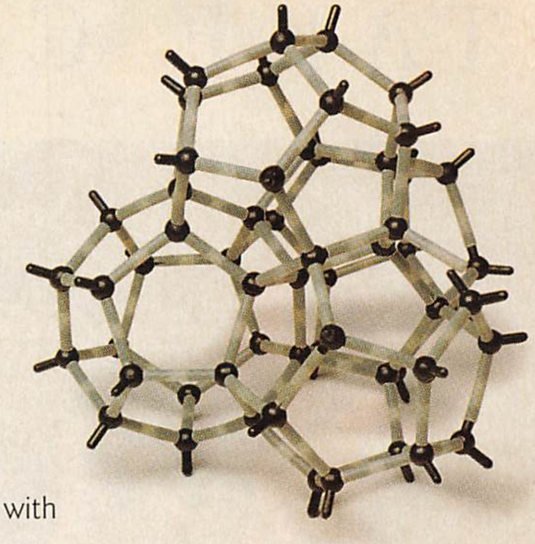
His students have already written their acceptance speeches for the biggest prize in science.



Never let it be said that Kenneth Cutler sets easy goals for his STARS (Students Training As Research Scientists). To acquaint them with the real world of scientific exploration, his students formulate in-depth research papers and even submit grant proposals to fund their projects. Then, to experience just how far scientific research can take them, students present a formal speech thanking the King of Sweden for awarding them the most prestigious prize in science.

This combination of problem-solving, creative writing, and public speaking stimulates both left-brain and right-brain thinking. It also demonstrates the benefits of a scientific career to students who might not normally consider it. For showing his students science can be rewarding, stimulating, and even "cool," State Farm is pleased to present Kenneth Cutler with our Good Neighbor Award® and to present $5,000 to the Hillside High chapter of NC Student Academy of Science, in Durham, North Carolina.

Now it's his turn to prepare an acceptance speech.

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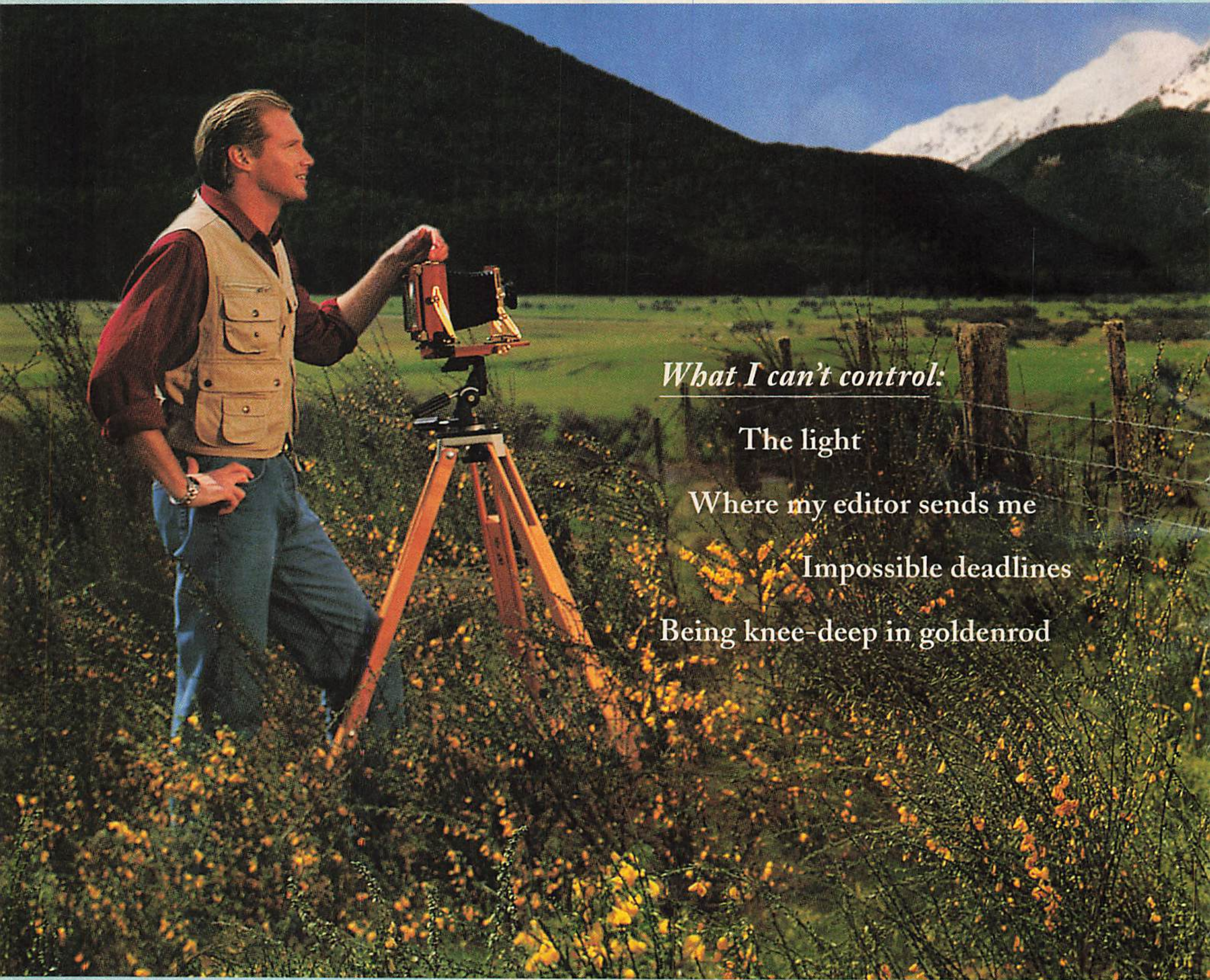
What I can't control:
The light
Where my editor sends me
Impossible deadlines
Being knee-deep in goldenrod

Talk to your doctor about once-a-day, nondrowsy CLARITIN-D® 24 HOUR — for people ages 12 and up. CLARITIN-D® 24 HOUR is safe to take as prescribed: one tablet daily. In studies, dry mouth was the most commonly reported side effect. Other side effects including drowsiness and sleeplessness occurred about as often as they did with a sugar pill.

Some people should not take CLARITIN-D® 24 HOUR. If you have a history of difficulty in swallowing tablets or any medical problems associated with swallowing abnormalities, you should not take CLARITIN-D® 24 HOUR. Due to pseudoephedrine (the decongestant in CLARITIN-D® 24 HOUR tablets and many over-the-counter allergy medications), you should not take CLARITIN-D® 24 HOUR if you have glaucoma (abnormally high pressure in your eyes), difficulty urinating, severe high blood pressure, severe heart disease, or are taking MAO inhibitors (certain prescription medications that treat depression).

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Extended Release Tablets
For stuffy nose and other seasonal allergy symptoms

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CLARITIN-D® 24 HOUR
brand of loratadine and pseudoephedrine sulfate, USP
Extended Release Tablets

BRIEF SUMMARY
(For full Prescribing Information, see package insert.)

INDICATIONS AND USAGE: CLARITIN-D 24 HOUR Extended Release Tablets are indicated for the relief of symptoms of seasonal allergic rhinitis. CLARITIN-D 24 HOUR Extended Release Tablets should be administered when both the antihistaminic properties of CLARITIN® (loratadine) and the nasal decongestant activity of pseudoephedrine sulfate are desired (see **CLINICAL PHARMACOLOGY** section).

CONTRAINDICATIONS: CLARITIN-D 24 HOUR Extended Release Tablets are contraindicated in patients who are hypersensitive to this medication or to any of its ingredients.

This product, due to its pseudoephedrine component, is contraindicated in patients with narrow-angle glaucoma or urinary retention, and in patients receiving monoamine oxidase (MAO) inhibitor therapy or within fourteen (14) days of stopping such treatment. (See **PRECAUTIONS: Drug Interactions** section.) It is also contraindicated in patients with severe hypertension, severe coronary artery disease, and in those who have shown hypersensitivity or idiosyncrasy to its components, to adrenergic agents, or to other drugs of similar chemical structures. Manifestations of patient idiosyncrasy to adrenergic agents include: insomnia, dizziness, weakness, tremor, or arrhythmias.

WARNINGS: CLARITIN-D 24 HOUR Extended Release Tablets should be used with caution in patients with hypertension, diabetes mellitus, ischemic heart disease, increased intraocular pressure, hyperthyroidism, renal impairment, or prostatic hypertrophy. Central nervous system stimulation with convulsions or cardiovascular collapse with accompanying hypotension may be produced by sympathomimetic amines.

Use in Patients Approximately 60 Years of Age and Older: The safety and efficacy of CLARITIN-D 24 HOUR Extended Release Tablets in patients greater than 60 years old have not been investigated in placebo-controlled clinical trials. The elderly are more likely to have adverse reactions to sympathomimetic amines.

PRECAUTIONS: General: Because there have been reports of esophageal obstruction and perforation in patients who have taken a previously marketed formulation of CLARITIN-D 24 HOUR Extended Release Tablets, it is recommended that patients who have a history of difficulty in swallowing tablets or who have known upper gastrointestinal narrowing or abnormal esophageal peristalsis not use this product. Furthermore, since it is not known whether this formulation of CLARITIN-D 24 HOUR Extended Release Tablets has the potential for this adverse event, it is reasonable to recommend that all patients take this product with a full glass of water (see **PRECAUTIONS: Information for Patients, ADVERSE REACTIONS, DOSAGE AND ADMINISTRATION**). Because the doses of this fixed combination product cannot be individually titrated and hepatic insufficiency results in a reduced clearance of loratadine to a much greater extent than pseudoephedrine, CLARITIN-D 24 HOUR Extended Release Tablets should generally be avoided in patients with hepatic insufficiency. Patients with renal insufficiency (GFR <30 mL/min) should be given a lower initial dose (one tablet every other day) because they have reduced clearance of loratadine and pseudoephedrine.

Information for Patients: Patients taking CLARITIN-D 24 HOUR Extended Release Tablets should receive the following information: CLARITIN-D 24 HOUR Extended Release Tablets are prescribed for the relief of symptoms of seasonal allergic rhinitis. Patients should be instructed to take CLARITIN-D 24 HOUR Extended Release Tablets only as prescribed and not to exceed the prescribed dose. Patients should also be advised against the concurrent use of CLARITIN-D 24 HOUR Extended Release Tablets with over-the-counter antihistamines and decongestants. Patients who have a history of difficulty in swallowing tablets or who have known upper gastrointestinal narrowing or abnormal esophageal peristalsis should not use this product.

This product should not be used by patients who are hypersensitive to it or to any of its ingredients. Due to its pseudoephedrine component, this product should not be used by patients with narrow-angle glaucoma, urinary retention, or by patients receiving a monoamine oxidase (MAO) inhibitor or within 14 days of stopping use of an MAO inhibitor. It also should not be used by patients with severe hypertension or severe coronary artery disease.

Patients who are or may become pregnant should be told that this product should be used in pregnancy or during lactation only if the potential benefit justifies the potential risk to the fetus or nursing infant.

Patients should be instructed not to break or chew the tablet and to take it with a full glass of water (see **PRECAUTIONS: General, ADVERSE REACTIONS, DOSAGE AND ADMINISTRATION**).

Drug Interactions: No specific interaction studies have been conducted with CLARITIN-D 24 HOUR Extended Release Tablets. However, loratadine (10 mg once daily) has been safely coadministered with therapeutic doses of erythromycin, cimetidine, and ketoconazole in controlled clinical pharmacology studies. Although increased plasma concentrations (AUC 0-24 hrs) of loratadine and/or descarboethoxyloratadine were observed following coadministration of loratadine with each of these drugs in normal volunteers (n = 24 in each study), there were no clinically relevant changes in the safety profile of loratadine, as assessed by electrocardiographic parameters, clinical laboratory tests, vital signs, and adverse events. There were no significant effects on QT_c intervals, and no reports of sedation or syncope. No effects on plasma concentrations of cimetidine or ketoconazole were observed. Plasma concentrations (AUC 0-24 hrs) of erythromycin decreased 15% with coadministration of loratadine relative to that observed with erythromycin alone. The clinical relevance of this difference is unknown. These above findings are summarized in the following table:

Effects on Plasma Concentrations (AUC 0-24 hrs) of Loratadine and Descarboethoxyloratadine After 10 Days of Coadministration (Loratadine 10 mg) in Normal Volunteers

	Loratadine	Descarboethoxy-loratadine
Erythromycin (500 mg Q8h)	+ 40%	+46%
Cimetidine (300 mg QID)	+103%	+ 6%
Ketoconazole (200 mg Q12h)	+307%	+73%

There does not appear to be an increase in adverse events in subjects who received oral contraceptives and loratadine.

CLARITIN-D 24 HOUR Extended Release Tablets (pseudoephedrine component) are contraindicated in patients taking monoamine oxidase inhibitors and for 2 weeks after stopping use of an MAO inhibitor. The antihypertensive effects of beta-adrenergic blocking agents, methyldopa, mecamylamine, reserpine, and veratrum alkaloids may be reduced by sympathomimetics. Increased ectopic pacemaker activity can occur when pseudoephedrine is used concomitantly with digitalis.

Drug/Laboratory Test Interactions: The *in vitro* addition of pseudoephedrine to sera containing the cardiac isoenzyme MB of serum creatinine phosphokinase progressively inhibits the activity of the enzyme. The inhibition becomes complete over 6 hours.

Carcinogenesis, Mutagenesis, Impairment of Fertility: There are no animal or laboratory studies on the combination product loratadine and pseudoephedrine sulfate to evaluate carcinogenesis, mutagenesis, or impairment of fertility.

In an 18-month carcinogenicity study in mice and a 2-year study in rats loratadine was administered in the diet at doses up to 40 mg/kg (mice) and 25 mg/kg (rats). In the carcinogenicity studies pharmacokinetic assessments were carried out to determine animal exposure to the drug. AUC data demonstrated that the exposure of mice given 40 mg/kg of loratadine was 3.6 (loratadine) and 18 (active metabolite) times higher than in humans given the maximum recommended daily oral dose. Exposure of rats given 25 mg/kg of loratadine was 28 (loratadine) and 67 (active metabolite) times higher than in humans given the maximum recommended daily oral dose. Male mice given 40 mg/kg had a significantly higher incidence of hepatocellular tumors (combined adenomas and carcinomas) than concurrent controls. In rats, a significantly higher incidence of hepatocellular tumors (combined adenomas and carcinomas) was observed in males given 10 mg/kg and in males and females given 25 mg/kg. The clinical significance of these findings during long-term use of loratadine is not known.

Two-year feeding studies in mice and rats conducted under the auspices of the National Toxicology Programs (NTP) uncovered no evidence of carcinogenic potential of ephedrine sulfate at doses up to 10 and 27 mg/kg, respectively (approximately 16% and 100% of the maximum recommended human daily oral dose of pseudoephedrine sulfate on a mg/m^2 basis).

In mutagenicity studies with loratadine alone, there was no evidence of mutagenic potential in reverse (Ames) or forward point mutation (CHO-HGPRT) assays, or in the assay for DNA damage (Rat Primary Hepatocyte Unscheduled DNA Assay) or in two assays for chromosomal aberrations (Human Peripheral Blood Lymphocyte Clastogenesis Assay and the Mouse Bone Marrow Erythrocyte Micronucleus Assay). In the Mouse Lymphoma Assay, a positive finding occurred in the nonactivated but not the activated phase of the study.

Decreased fertility in male rats, shown by lower female conception rates, occurred at 64 mg/kg of loratadine (approximately 50 times the maximum recommended human daily oral dose based on mg/m^2) and was reversible with cessation of dosing. Loratadine had no effect on male or female fertility or reproduction in the rat at 24 mg/kg (approximately 20 times the maximum recommended human daily oral dose on a mg/m^2 basis).

Pregnancy Category B: The combination product loratadine and pseudoephedrine sulfate was evaluated for teratogenicity in rats and rabbits. There was no evidence of teratogenicity in reproduction studies with this combination of the same clinical ratio (1:24) at oral doses up to 150 mg/kg (approximately 5 times the maximum recommended human daily oral dose on a mg/m^2 basis) in rats, and 120 mg/kg (8 times the maximum recommended human daily oral dose on a mg/m^2 basis) in rabbits. Similarly, no evidence of animal teratogenicity in rats and rabbits was reported at oral doses up to 96 mg/kg of loratadine alone (approximately 75 and 150 times, respectively, the maximum human daily oral dose on a mg/m^2 basis). There are, however, no adequate and well-controlled studies in pregnant women. Because animal reproduction studies are not always predictive of human response, CLARITIN-D 24 HOUR Extended Release Tablets should be used during pregnancy only if clearly needed.

Nursing Mothers: It is not known if this combination product is excreted in human milk. However, loratadine when administered alone and its metabolite descarboethoxyloratadine pass easily into breast milk and achieve concentrations that are equivalent to plasma levels, with an AUC_{milk}/AUC_{plasma} ratio of 1.17 and 0.85 for the parent and active metabolite, respectively. Following a single oral dose of 40 mg, a small amount of loratadine and metabolite was excreted into the breast milk (approximately 0.03% of 40 mg over 48 hours). Pseudoephedrine administered alone also distributes into breast milk of the lactating human female. Pseudoephedrine concentrations in milk are consistently higher than those in plasma. The total amount of drug in milk as judged by the area under the curve (AUC) is 2 to 3 times greater than in plasma. The fraction of a pseudoephedrine dose excreted in milk is estimated to be 0.4% to 0.7%. A decision should be made whether to discontinue nursing or to discontinue the drug, taking into account the importance of the drug to the mother. Caution should be exercised when CLARITIN-D 24 HOUR Extended Release Tablets are administered to a nursing woman.

Pediatric Use: Safety and effectiveness in children below the age of 12 years have not been established.

ADVERSE REACTIONS: Information on adverse reactions is provided from placebo-controlled studies involving over 2000 patients, 605 of whom received CLARITIN-D 24 HOUR Extended Release Tablets once daily for up to 2 weeks. In these studies, the incidence of adverse events reported with CLARITIN-D 24 HOUR Extended Release Tablets was similar to those reported with twice-daily (q12h) 120 mg sustained-release pseudoephedrine alone.

REPORTED ADVERSE EVENTS WITH AN INCIDENCE OF ≥2% IN CLARITIN-D 24 HOUR EXTENDED RELEASE TABLETS TREATMENT GROUP IN DOUBLE-BLIND, RANDOMIZED, PLACEBO-CONTROLLED CLINICAL TRIALS

PERCENT OF PATIENTS REPORTING

	CLARITIN-D® 24 HOUR (n = 605)	Loratadine 10 mg (n = 449)	Pseudo-ephedrine 120 mg q12h (n = 220)	Placebo (n = 605)
Dry Mouth	8	2	7	2
Somnolence	6	4	5	4
Insomnia	5	1	9	1
Pharyngitis	5	5	5	5
Dizziness	4	2	3	2
Coughing	3	2	3	1
Fatigue	3	4	1	2
Nausea	3	2	4	2
Nervousness	3	1	4	1
Anorexia	2	<1	2	0
Dysmenorrhea	2	2	2	1

Adverse events occurring in greater than or equal to 2% of CLARITIN-D 24 HOUR Extended Release Tablets-treated patients, but that were more common in the placebo-treated group, include headache.

Adverse events did not appear to significantly differ based on age, sex, or race, although the number of non-whites was relatively small.

In addition to those adverse events reported above, the following adverse events have been reported in fewer than 2% of patients who received CLARITIN-D 24 HOUR Extended Release Tablets:

Autonomic Nervous System: Altered lacrimation, flushing, increased sweating, mydriasis, thirst.

Body As A Whole: Abnormal vision, asthenia, back pain, chest pain, conjunctivitis, earache, eye pain, facial edema, fever, flu-like symptoms, leg cramps, lymphadenopathy, malaise, rigors, tinnitus.

Cardiovascular System: Hypertension, palpitation, tachycardia.

Central and Peripheral Nervous System: Convulsions, dysphonia, hyperkinesis, hypertonia, migraine, paresthesia, tremor.

Gastrointestinal System: Abdominal distension, altered taste, constipation, diarrhea, dyspepsia, flatulence, gastritis, stomatitis, tongue ulceration, toothache, vomiting.

Liver and Biliary System: Cholelithiasis.

Musculoskeletal System: Arthralgia, musculoskeletal pain, myalgia, tendinitis.

Psychiatric: Agitation, depression, emotional lability, irritability.

Reproductive System: Vaginitis.

Resistance Mechanism: Abscess, viral infection.

Respiratory System: Bronchospasm, dyspnea, epistaxis, hemoptysis, nasal congestion, nasal irritation, pleurisy, pneumonia, sinusitis, sputum increased, wheezing.

Skin and Appendages: Acne, pruritus.

Urinary System: Oliguria, micturition frequency, urinary retention, urinary tract infection.

Additional adverse events reported with the combination of loratadine and pseudoephedrine include abnormal hepatic function, aggressive reaction, anxiety, apathy, confusion, euphoria, paroniria, postural hypotension, syncope, urticaria, vertigo, weight gain.

The following additional adverse events have been reported with CLARITIN Tablets: abdominal distress, alopecia, altered micturition, altered salivation, amnesia, anaphylaxis, angioneurotic edema, blepharospasm, breast enlargement, breast pain, bronchitis, decreased libido, dermatitis, dry hair, dry skin, erythema multiforme, hypoesthesia, impaired concentration, impotence, increased appetite, laryngitis, menorrhagia, nasal dryness, peripheral edema, photosensitivity reaction, purpura, rash, seizures, sneezing, supraventricular tachyarrhythmias, upper respiratory infection, urinary discoloration.

Pseudoephedrine may cause mild CNS stimulation in hypersensitive patients. Nervousness, excitability, restlessness, dizziness, weakness, or insomnia may occur. Headache, drowsiness, tachycardia, palpitation, pressor activity, and cardiac arrhythmias have been reported. Sympathomimetic drugs have also been associated with other untoward effects, such as fear, anxiety, tenseness, tremor, hallucinations, seizures, pallor, respiratory difficulty, dysuria, and cardiovascular collapse.

There have been postmarketing reports of mechanical upper gastrointestinal tract obstruction and esophageal perforation in patients taking a previously marketed formulation of CLARITIN-D 24 HOUR Extended Release Tablets. In some, but not all, of these cases, patients have had known upper gastrointestinal narrowing or abnormal esophageal peristalsis. It is not known whether this reformulation of CLARITIN-D 24 HOUR Extended Release Tablets has the potential for this adverse event (see **PRECAUTIONS, DOSAGE AND ADMINISTRATION**).

OVERDOSAGE: In the event of overdosage, general symptomatic and supportive measures should be instituted promptly and maintained for as long as necessary. Treatment of overdosage would reasonably consist of emesis (ipecac syrup), except in patients with impaired consciousness, followed by the administration of activated charcoal to absorb any remaining drug. If vomiting is unsuccessful, or contraindicated, gastric lavage should be performed with normal saline. Saline cathartics may also be of value for rapid dilution of bowel contents. Loratadine is not eliminated by hemodialysis. It is not known if loratadine is eliminated by peritoneal dialysis.

Somnolence, tachycardia, and headache have been reported with doses of 40 to 180 mg of loratadine. In large doses, sympathomimetics may give rise to giddiness, headache, nausea, vomiting, sweating, thirst, tachycardia, precordial pain, palpitations, difficulty in micturition, muscular weakness and tenseness, anxiety, restlessness, and insomnia. Many patients can present a toxic psychosis with delusions and hallucinations. Some may develop cardiac arrhythmias, circulatory collapse, convulsions, coma, and respiratory failure.

The oral median lethal dose for the mixture of the two drugs was greater than 525 and 1839 mg/kg in mice and rats, respectively (approximately 10 and 58 times the maximum recommended human daily oral dose on a mg/m^2 basis). The oral median lethal dose for loratadine was greater than 5000 mg/kg in rats and mice (greater than 2000 times the maximum recommended human daily oral dose on a mg/m^2 basis). Single oral doses of loratadine showed no effects in rats, mice, and monkeys at doses as high as 10 times the maximum recommended human daily oral dose on a mg/m^2 basis.

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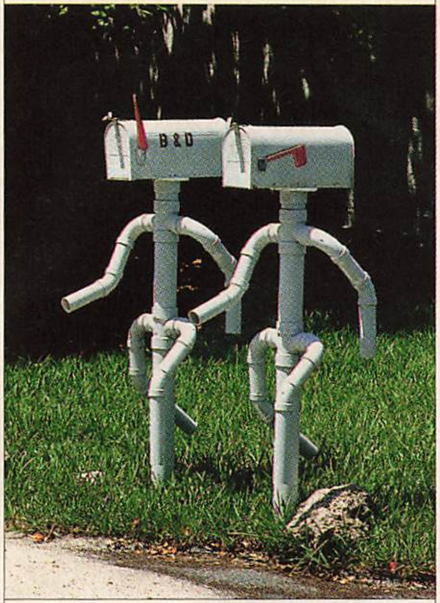

JO WILLIAMS/THE IMAGE FINDERS

GOOD SCIENCE, BAD SCIENCE

I was severely disappointed with the August issue of *Discover.* If one defines intelligence as critical, evidence-based thinking, then your editorial board and reporters are deficient in this characteristic. Your articles "Worrying About Milk" and "Heresy" are devoid of the applications of scientific thinking that must be exercised by any magazine purporting to be a scientific publication. It appears that you do not appreciate the difference between causation and correlation. I expect at least that from my sources of scientific information. These articles should have appeared in journals that report advances in the fantasy world of ESP, where accurate scientific studies are not necessary.

ROBIN OXMAN, M.D.
Huntington Beach, California

Kudos on your daring August issue! Would that all science magazines reserved some space for "news that challenges comfortable ideas and accepted wisdom." The importance of agitation in the scientific community (often funded by private interests) is not lost on me; any science that refuses to accept a challenge is not good science. Congratulations on giving a voice to controversial researchers.

AMANDA WERHANE
Oakland, California

As a physician and nurse, I agree that discouraging everyone from drinking cow's milk is a smart idea. Dairy is implicated in many serious health problems: heart disease, ovarian cancer, childhood-onset diabetes, colic, breast cancer, and asthma.

In June 1999, a dairy executive at the "Calcium Summit" in Washington, D.C., bragged that his industry especially targeted moms, kids, and college students. It's vital for those groups, and the rest of us, not to swallow all those paid celebrity milk-mustache ads and clever "Got Milk?" pitches and realize that no one needs to drink cow's milk to ward off osteoporosis and bone breaks. Yes, we all require calcium. But we can easily meet our needs through fortified fruit juices, beans, calcium-set tofu, and leafy green vegetables. Other bone-protecting steps include not smoking, minimizing sodium intake, avoiding animal protein, doing weight-bearing exercises, and getting vitamin D from a few minutes of daily sun exposure, fortified breakfast cereals and soy milks, or a multivitamin supplement.

PATRICE GREEN, M.D.
Baltimore, Maryland

So T. Colin Campbell thinks it's strange that we're the only species that suckles the milk of another species? That's a great sound bite, but it has no significance in scientific inquiry. Did he do a controlled study that showed rats who drank milk from a blue whale had more cancer than those who ate soybeans from a farmer's bin? We're also the only species that plays Mozart; that doesn't necessarily make it good or bad for our health.

Most of Campbell's conclusions are based on poor cross-cultural studies. Even the Harvard Nurses' Health Study is suspect because respondents reported their own dietary habits, and it seems to me that people tend to exaggerate their consumption of good foods (milk?) when asked about their eating habits.

Finally, when will dietary researchers in this country realize that people do not eat what they are told to eat? They eat what they like. Farmers grow certain foods because over the years consumers have spoken at the checkout line. To imply that farmers and government nutritionists are foisting unhealthy foods on an unsuspecting public just feeds into the current thinking that we're not responsible for our own actions anymore.

PATRICK MAXWELL
Newport, New York

I am a retired veterinarian, having doctored horses and cattle for 25 years. Your article on milk brought back many memories. When farmers kept a milk cow on the farm for the weaner calves, there were few digestive problems. But when no dairy cows were available, the farmers bought milk for the calves to drink.

I soon found that these calves could not digest pasteurized, homogenized milk. Homogenization breaks the fat globule into such small bits that it doesn't curd in the stomach and passes directly into the small intestine, where it created a severe inflammation in the calves. I treated them with goat's milk, which has the largest fat globule of any milk found on the farm. Most of the calves I treated made a quick recovery.

I, too, drank milk on the farm, and I never had any adverse effects. But in college I started drinking store-bought milk, which acted like poison on my system. Fifty years later, a friend with a milk cow offered me some milk. I accepted, and for three years now I've been drinking milk as I did on the farm, with no adverse side effects.

EARL D. SMITH, D.V.M.
Parachute, Colorado

I greatly appreciated that Brad Lemley, the author of "Heresy," identified Rupert Sheldrake's body of work with David Bohm's interpretation of quantum theory. However, Lemley greatly distorted the plausibility and degree of acceptance that Bohm's ideas enjoy.

The experiments of Alain Aspect noted by Lemley hardly count as strong support for Bohm. In fact, they were widely recognized as settling the debate over "hidden variable" explanations of quantum theory in favor of the "Copenhagen" interpretation, [which

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states that the act of observing affects the nature of reality at the subatomic level].

This reading of quantum mechanics eliminates the need for hidden variables like those postulated by Bohm (and of course Sheldrake's "morphic fields" are hidden variables writ large). It is true that Bohm's interpretation can be made consistent with the findings, but only after violating relativity theory, a problem the Copenhagen reading does not share.

While I for one have little time for Sheldrake's ideas, I applaud *Discover* for giving unusual notions like this a public hearing. Mainstream science is ill served by presenting itself dogmatically, as some of Sheldrake's critics do.

DAN McARTHUR
Ottawa, Ontario

Kudos on your article on Rupert Sheldrake. His "heresies" are knowledge ahead of its time. Current science may look at DNA as the "root of life," but DNA of and by itself is as lifeless as the coils, condensers, and wiring in a TV set. You don't find the picture by looking at the wiring. Raw DNA is merely the tuning mechanism that resonates to a particular morphic field, which is unfolded and out-pictured into a biological life-form.

BILL SHEPPARD
San Francisco, California

NEITHER NATURE NOR NURTURE?

Your article about Mark Flinn's study of cortisol levels in Dominican children ["Family Matters," August] gave readers the misleading impression that Flinn's results are in conflict with my theory of child development. In fact, Flinn and I have great respect for each other's work. Our views are not in conflict because we are talking about different things.

My book is about the long-term effects of childhood experiences—not playground quarrels of the sort described in the article but (for example) those of the child who is subjected to day-to-day denigration by his peers over a period of years. Being yelled at by one's parents is undoubtedly stressful, but the evidence summarized in my book indicates that it has no measurable effects on adult personality. This makes evolutionary sense, because children are not destined to spend their adult lives with their parents.

Why do children have some of the same personality strengths and weaknesses as their parents? The answer (based not just on studies of identical twins reared apart but on hundreds of studies, using a variety of methods) is simple: heredity. My theory was designed to answer a more difficult question: How do we account for the differences in personality that can be explained neither by heredity nor by "nurture" (the way children are treated by their parents)? My answer has to do with the experiences children have outside the parental home, which is where they *are* destined to spend their adult lives.

JUDITH RICH HARRIS
Author, *The Nurture Assumption*
Middletown, New Jersey

ERRATA

In "Why Has Our Weather Gone Wild?" (June), we should have credited NOAA/GFDL, from a report by T. Delworth, K. Dixon, and T. Knutson, as the source for the map that appears on page 76.

On page 40 in the August Sky Lights, we misidentified the *Apollo 12* astronaut in the photo as Pete Conrad. He is actually astronaut Alan Bean.

In "The Panther Mountain Crater" (August), we stated on page 59 that iridium is a chemical produced in the heat and pressure of meteorite impacts. Iridium is an element often found in meteorites and spread on impact.

HELP FROM DISCOVER

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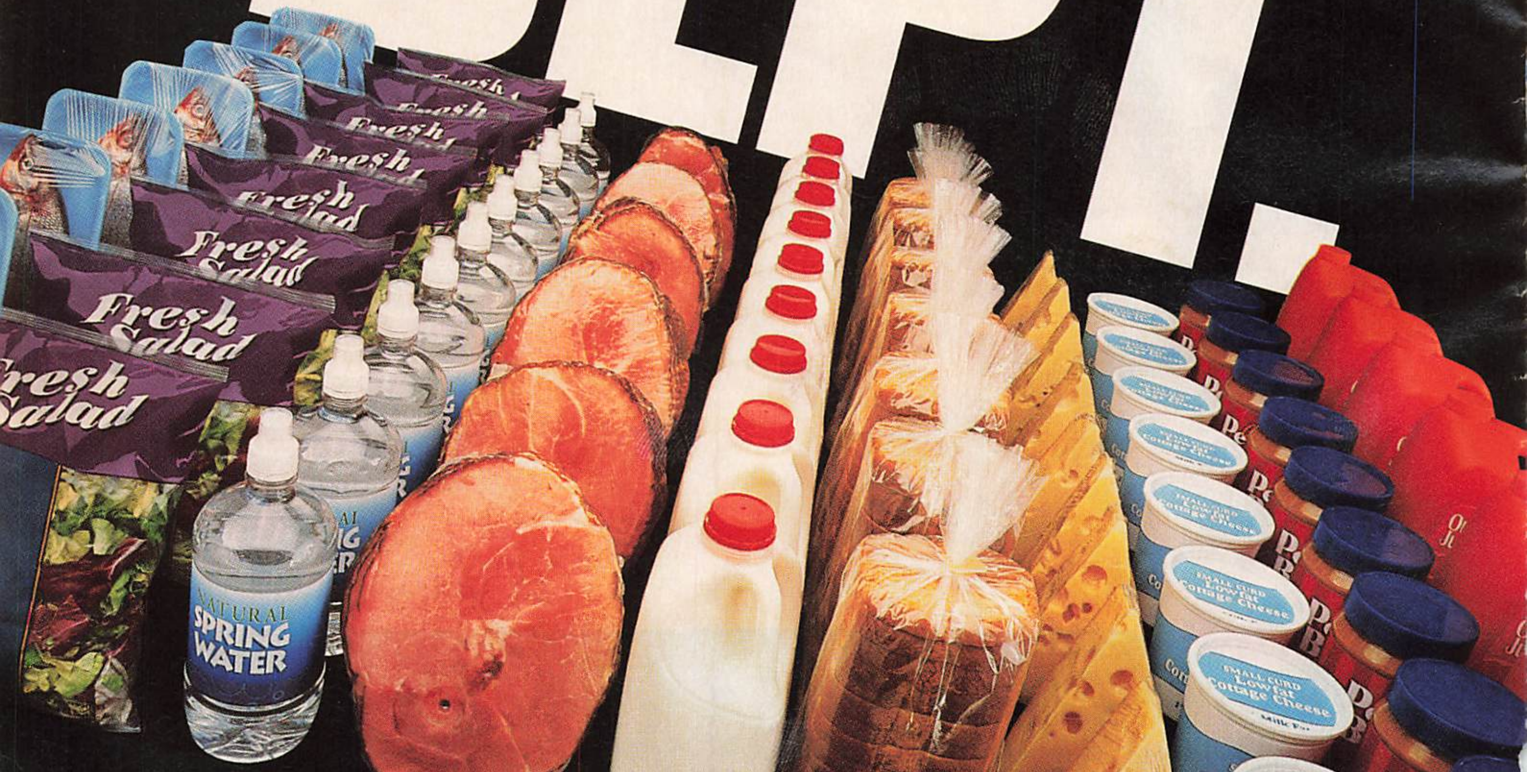
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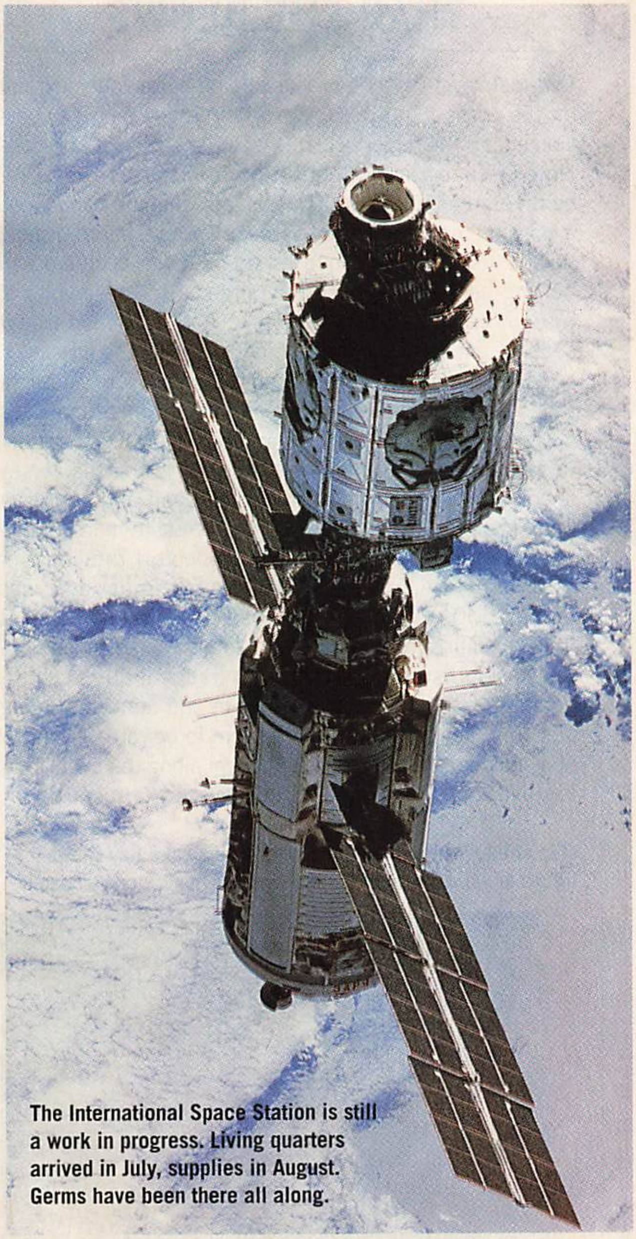


The International Space Station is still a work in progress. Living quarters arrived in July, supplies in August. Germs have been there all along.

LEFT: NASA/SPL/PHOTO RESEARCHERS; RIGHT: MARK REINSTEIN/FPG INTERNATIONAL

ODOR ENGINEERS

Inbred flowers often have disappointingly banal aromas—and that's a problem for farmers as much as for romantics. Plants that have been selected for their large fruit or bold blooms often have little energy left over for the manufacture of sweet smells. Without a strong fragrance, the plants have trouble attracting pollinating bees and birds. But help is on the way. Natalia Dudareva, a plant molecular biologist at Purdue University, recently isolated the gene for methyl benzoate, a major component of the scent of snapdragons (right). This gene seems to be a blueprint for plant smell: Some 30 to 40 other agriculturally important plants, including tobacco and the petunia, use the same smell-generation system. Intensive breeding evidently deactivates the gene. Dudareva plans to put additional copies of the key DNA into de-scented flowers to restore their scent—or even impart entirely new aromas to naturally odor-impaired blooms. "If we can increase scent, for example, to apple trees, the flowers will attract more pollinators or recruit new foragers. And that means better fruit quality," she says. *—Josie Glausiusz*

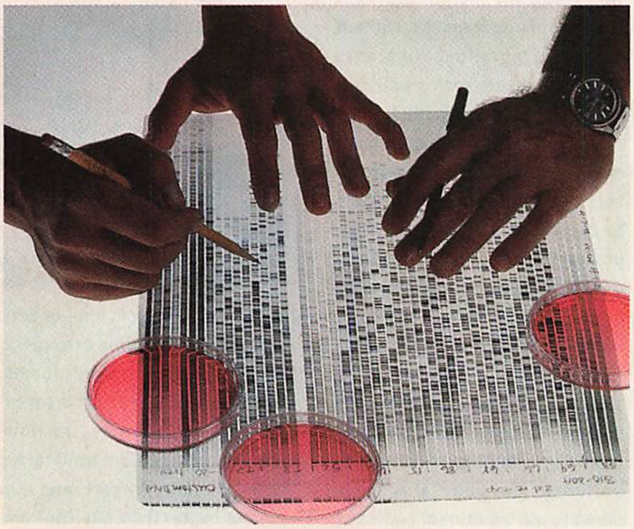
Bugs in Space

When the International Space Station's first permanent crew arrives next month, it will have to perform an unintended science experiment—learning to fight mildew in orbit. If Russia's *Mir* space station is any indication, the astronauts will find space bugs are as common as the stink in an old sneaker.

"I'm sure there are some pathogens on the International Space Station already, because we've made no attempt to sterilize materials before sending them to the station. We don't consider it a problem," says Duane Pierson, head of the microbiology program at NASA's Johnson Space Center. But unwanted fungal passengers have made trouble aboard *Mir*, eating away at windows and destroying electronic equipment. "I think most of the difficulties on *Mir* have been due to localized areas of high humidity, because fungi and bacteria like to grow in wet places," Pierson says. "The International Space Station was designed to prevent condensation buildup." All food and water sent to the station will be screened for menacing microbes, and filters will scrub pathogens from the air.

One thing the crew won't be doing is spraying the $30 billion-plus space station with supermarket-variety antibacterial products. High radiation levels in Earth's orbit speed the rate of mutations, and spraying might just hasten the arrival of resistant strains. "For the most part, the crew will clean with regular surfactants—plain old soap." *—Kathy A. Svitil*

The Emperor's New Genome?



The human eye can pick out genetic signatures but cannot piece together the whole genome. Even computers are barely up to the task.

You wouldn't know it from the press conferences, but scientists are still far from deciphering the human genome. About 20 to 30 percent of our genetic code—containing enigmatic chunks of repetitive DNA—is difficult to read using current sequencing methods, says genomicist David Schwartz of the University of Wisconsin-Madison. The rest has been sorted out only in bits and pieces. Schwartz likens the situation to reconstructing a book whose pages have been torn, ripped, and scattered. "You're missing some pages, and some are out of order, but you tape it together and say 'Aha! It's finished! I've got the book!' No, you don't. It's far from complete."

And it may take a long time before anyone benefits from the information in those tattered pages. In theory, understanding how genes cause disease could lead to new targeted drugs or therapies. But epidemiologist Neil Holtzman of Johns Hopkins points out that many disorders—such as asthma, hypertension, and heart disease—result from some complex interactions between numerous genes and environmental factors. Even diseases caused by a single mutant gene cannot necessarily be cured, he says. For instance, researchers discovered the genetic basis for sickle-cell anemia more than 40 years ago, yet they still haven't developed a definitive treatment for it.

"I don't disagree that some of this has been overstated," says Craig Venter, whose company, Celera Genomics, developed the rapid sequencing techniques that helped nudge along the Human Genome Project. "But I think it's an important beginning. It will be viewed as a bright line in history because of what we can do now that we have this information, not just because of the information itself." *—Josie Glausiusz*

Science Myth

MYTH: The directional needle in a compass points to Earth's north magnetic pole, which identifies true, geographic north.

FACT: Magnets are attracted to opposite poles, so the north end of a compass needle seeks out a south pole—in other words, that is magnetic south at the north pole. It is not at the geographic pole either. It sits in Canada, some 800 miles away, and it wanders constantly, moving about 10 miles a year. A compass gives only a rough indication of true north, especially in places like Alaska that are near the magnetic pole.

THAR SHE BLOWS

Evil-looking mile-wide cracks slicing across the seafloor off the coast of Virginia and North Carolina testify to past violence in the region. Neal Driscoll, a geologist at Woods Hole Oceanographic Institution in Massachusetts, recently startled many coastal residents when he announced a possible cause for the fissures. On a research cruise, he and his colleagues bounced sound waves off the ocean bottom near Chesapeake Bay and spotted reservoirs of buried, compressed natural gas. A disturbance might cause these gas reserves to blow, creating the cracks. If the event were big and fast enough, Driscoll says, it might trigger a submarine landslide and set off a tsunami.

Now a group at Pennsylvania State University has detected evidence of a similar upheaval along the Jersey shore. Graduate student Brandon Dugan and geologist Peter Flemings found a layer of high-pressure fluid trapped beneath the ocean bottom 100 miles off the coast of southern New Jersey. The 350-square-mile layer was formed 500,000 to 250,000 years ago when sediment from the Hudson River piled up and compressed the underlying siltlike sand. The fluid is trapped, but an earthquake could increase the pressure and send it surging out. Fortunately, these events seem to be rare. "The risk of a slope failure triggering a tsunami along the East Coast is small, but it is real," Driscoll says. *—Kathy A. Svitil*

Map of the seafloor near the lower Chesapeake Bay shows traces of giant landslides, which may have spawned tsunamis.

LEFT: DONAL PHILBY/FPG INTERNATIONAL; DR. NEAL DRISCOLL/WOODS HOLE OCEANOGRAPHIC INSTITUTION

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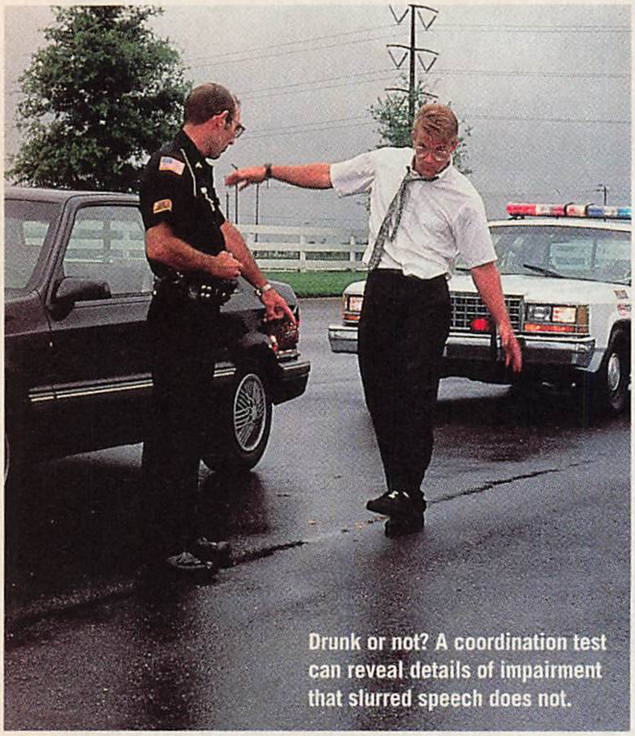

Drunk or not? A coordination test can reveal details of impairment that slurred speech does not.

Straight Talk

Bartenders, police officers, and hospital workers routinely identify drunks by their slurred speech. Several investigative groups judged the captain of the grounded *Exxon Valdez* oil tanker to be intoxicated based solely on the sound of his voice in his radio transmissions. But a team led by Harry Hollien, a phonetician at the University of Florida, has found that even self-proclaimed experts are pretty bad at estimating people's alcohol levels by the way they talk.

Hollien asked clinicians who treat chemical dependency, along with a group of everyday people, to listen to recordings made by volunteers when they were sober, then mildly intoxicated, legally impaired, and finally, completely smashed. Listeners consistently overestimated the drunkenness of mildly intoxicated subjects. Conversely, they underestimated the alcohol levels of those who were most inebriated. Professionals were little better at perceiving the truth than the ordinary joes. As a further test, Hollien asked actors to ham it up for the tape recorder. "They were very good at making people believe they were intoxicated when they weren't, and they were pretty doggone good at convincing the listener that they were not intoxicated when they were," says Hollien.

He thinks his research could encourage police to be more wary of snap judgments: Mild drinkers might come under needless suspicion, and seeming drunks can sometimes put up a surprisingly sober, dangerous fight. "I remember being on a train in World War II and there was a baby-faced sailor who acted real drunk. But when the patrol tried to subdue him, he suddenly turned into a Tasmanian devil," Hollien recalls. *—Fenella Saunders*

ROBOT WATCH: GOING ROBO-POSTAL

You've probably watched postal workers and wondered if they could move just a little faster. The United States Postal Service feels the same way. Over the past couple years, 58 of the nation's largest postal processing and distribution centers have started replacing manual mail sorters with high-speed robots. The machines come in two varieties: floor-standing robots mounted on a central pedestal and more versatile gantry robots that run along overhead tracks. Both are based on commercial assembly-line robots, modified to do tasks like lifting 300-pound loads of bulk mail and reading the post office's unique sorting instructions. "Let's say the mail comes into Chicago from the airlines," says John C. Weller, program manager of material-handling research and analysis for the Postal Service. "Each tray of mail has a bar-code label, which a scanner reads and transmits to the robot. It looks up that bar code and takes the tray to the matching station. It then loads containers to go to the different Chicago plants." The robots should help cut labor expenditures, which currently account for 80 percent of operating costs. No word on when dog-proof machines will replace the pooch-fearing mail carrier. *—Fenella Saunders*

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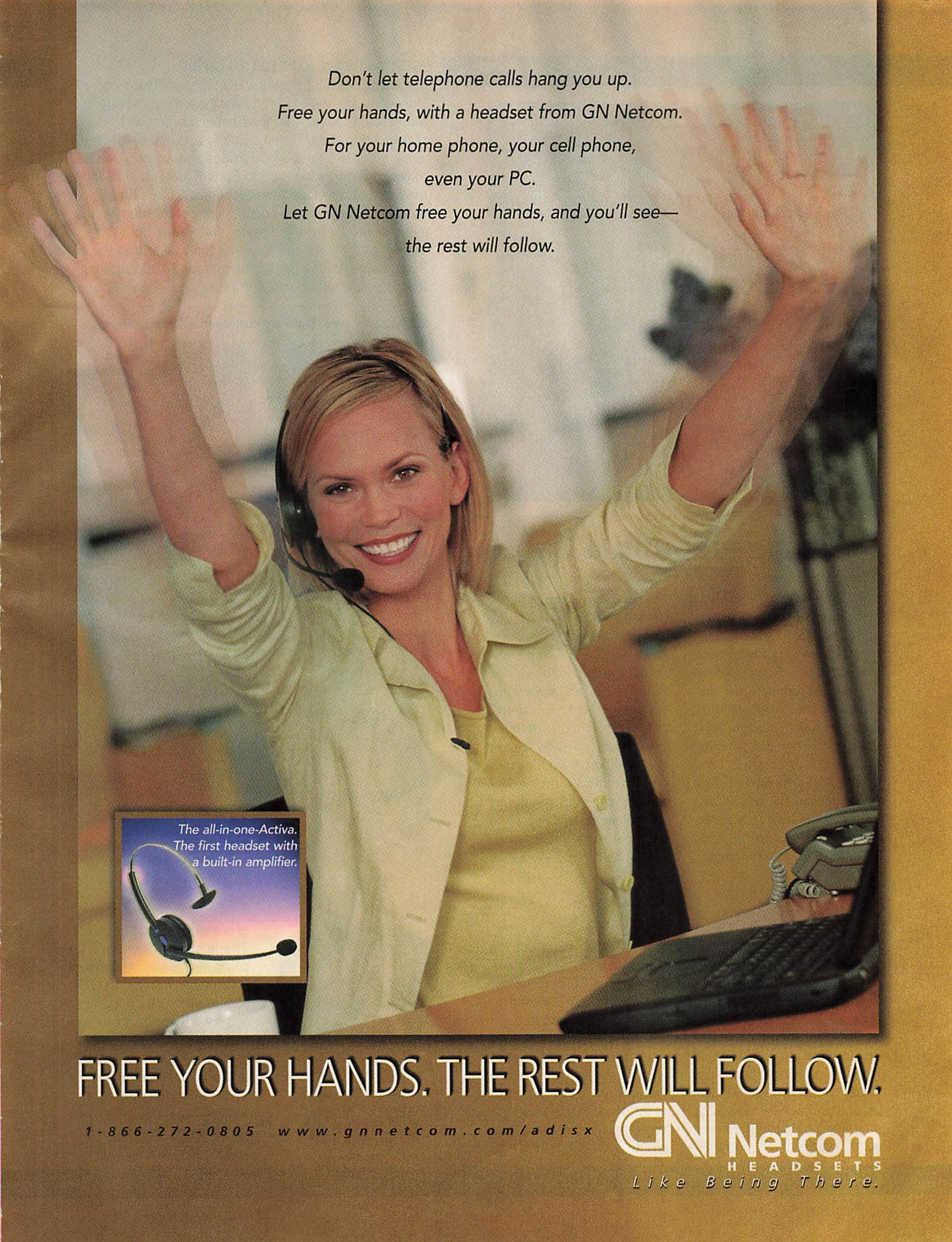

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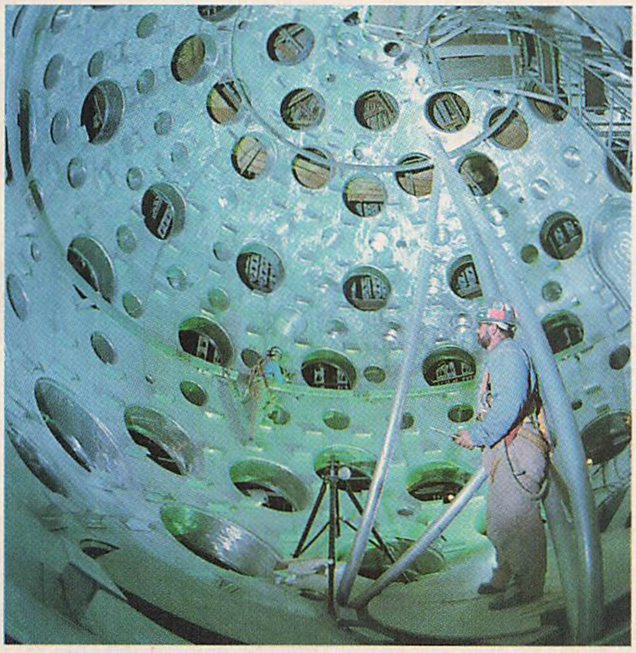


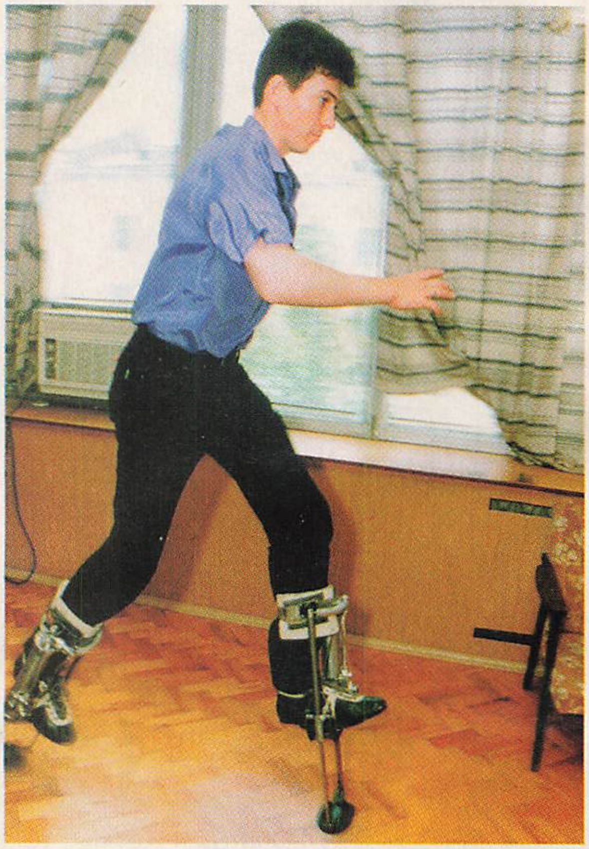
Armageddon in a Can

The weirdly beautiful aluminum globe above will be the new face of American atomic bomb testing, if it ever gets completed. The 30-foot-wide, 500-ton sphere is the centerpiece of the National Ignition Facility (NIF), a nuclear fusion machine under construction at Lawrence Livermore Laboratory in Livermore, California. NIF is designed to focus 192 laser beams onto a frozen hydrogen pellet the size of a BB, heating it to 100 million degrees Fahrenheit. That miniature conflagration is supposed to replicate the temperatures and pressures of an H-bomb, enabling engineers to maintain the United States' nuclear stockpile without detonating any weapons. But NIF, originally intended to be complete by 2004 at a cost of $1.2 billion, is running four years late and a stunning $2.7 billion over budget, prompting some members of Congress to call for suspending or terminating the project. *—Sara Pratt*

THESE BOOTS ARE MADE FOR GALLOPING

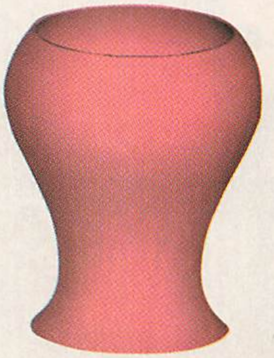
Some engineers at Russia's Ufa Aviation Technical University are walking with an extraordinary spring in their step. Gasoline-powered boots, originally conceived to scoot Soviet soldiers across a battlefield, allow them to take 14-foot strides and jog at up to 23 miles per hour, according to Boris Rydoi, chief of the project that developed the technology. Each time a brave soul wearing the boots takes a step, the gas in a cylinder fires, pushing a metal plate away from the bottom of the boot and shooting the walker into the air. Rydoi hopes to sell the *über*-boots for $400, pitching them as an alternative to in-line skates. *—Eric Powell*

Russia's new super-boots are cushioned with spring linings.



NEXT, THE COPIER WILL REPRODUCE POPSICLES

Does the world need a computer printer that spits out ice sculptures? Ming Leu, Wei Zhang, and their fellow mechanical engineers at the University of Missouri-Rolla think so. These days, industrial designers do a lot of their brainstorming with 3-D computer programs. But then they need to build physical prototypes or make molds and casts. So Leu and Zhang invented a device that constructs a 3-D model out of ice in a matter of hours, using a technique they call rapid-freeze prototyping. Following specifications from the computer, the machine moves back and forth inside a refrigerated container, squeezing out water droplets where needed. The water freezes and accumulates, layer by layer, into the shape of the desired part or object. Zhang says the ice printer could also fabricate detailed 3-D models of patients' MRI scans, which could assist in surgery. "Then the doctor can see through the patient's organs and know how he's going to do the operation," he says. *—Fenella Saunders*



Ice prototypes are faster and cheaper than plastic versions.

LEFT: BRYAN QUINTARD & JACQUELINE McBRIDE/LAWRENCE LIVERMORE NATIONAL LABORATORY; RIGHT: AP PHOTO/IVAN YELIZARYEV; BOTTOM: DR. MING LEU

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For now, only artists can picture conditions around a black hole.

Lab-Grown Black Holes

Physicists who study black holes—collapsed objects whose gravity is so potent not even light can escape—can't get anywhere close to their deadly quarry. So they are salivating at the news that two physicists, Ulf Leonhardt of the University of St. Andrews in Scotland and Paul Piwnicki of the Royal Institute of Technology in Stockholm, have uncovered a way to mimic a black hole with a small, safe vortex of cold atoms.

The key to lab-grown black holes, no bigger than raindrops, is to spin the atoms faster than the speed of light. Then, like swimmers caught in a violent whirlpool, passing beams of light get sucked into the current. Normally it would be impossible to move the atoms quickly enough. Last year, however, physicists at Harvard University found that light slows tremendously when it travels through a unique, low-temperature state of matter, called a Bose-Einstein condensate. The Harvard team braked light's speed to just 38 miles per hour.

Leonhardt and Piwnicki think a batch of frigid rubidium atoms could push the process further, until light crawls along at about an inch per second. "Then the vortex would have to spin at several feet per second, which is certainly possible. Optical black holes could be just a couple of years away," Leonhardt says. These atomic swirls will let the researchers test ideas about how black holes swallow matter and bend space, as predicted by Einstein's theory of relativity. *—Kathy A. Svitil*

ASK THE WIZARD » What makes each human voice distinct?
RUBY, NEW YORK, NEW YORK

Charles B. Simpson, of the Department of Otolaryngology at the University of Texas Health Science Center at San Antonio, answers:

Several components give the human voice its distinctive characteristics. The vocal cords provide the sound source for speech, while the lungs generate the airflow. The length and thickness of the vocal cords determine the pitch of the voice, but the cords contribute only a small part to the overall voice. At least as important are the resonating chambers of the throat and nasal cavities, which shape the unique sound of a person' s voice. Last, the muscles in the tongue, palate, and lips provide articulation—accent, lisp, etc. In combination, these factors allow a considerable amount of variation in voice characteristics. Individuals who are particularly gifted at imitating others' voices have excellent voluntary control of the muscles of the throat, tongue, and lips, enabling them to approximate the sound of another person' s voice.

LANDMARKS

October 10 20th anniversary of the completion of the Very Large Array, a huge radio telescope consisting of 27 linked mobile antennas riding 39 miles of tracks in the New Mexico desert near Socorro.

October 1,000th anniversary of Leif Eriksson's landing in North America, probably at present-day Nova Scotia or Newfoundland.

The exact date is unclear from historical accounts.

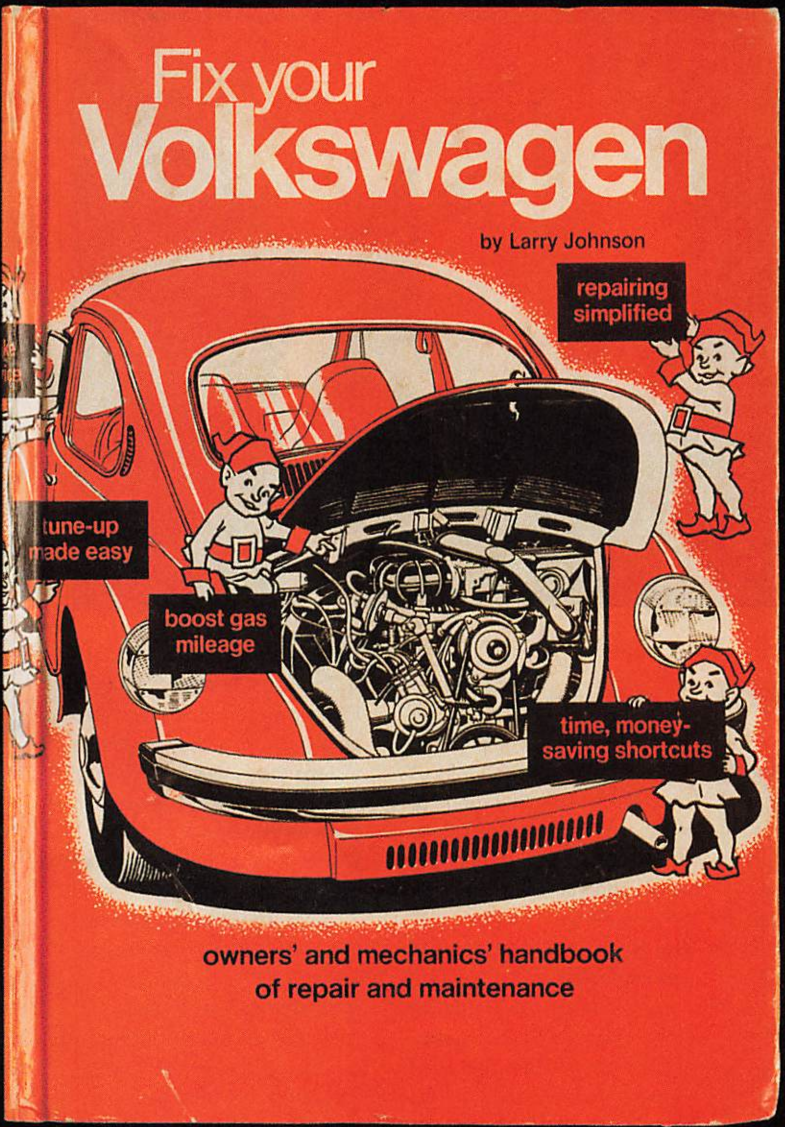
Died Nuclear physicist Marcus Oliphant, 98, on July 14. A key developer of the atom bomb, he later publicly denounced nuclear weaponry and called himself a "war criminal" for aiding in the bomb's creation.

Died Physicist and Albert Einstein biographer Abraham Pais, 82, on July 28. Pais's research helped explain why certain paired subatomic particles survive for unusually long periods before decaying.

Died Astrophysicist William Fastie, 83, on July 14. Fastie designed a spectrometer—an instrument for measuring the spectrum of light—rugged enough to withstand a rocket launch. His device has collected data on Jovian clouds and Martian riverbeds.

LEFT: ERICH SCHREMPP/PHOTO RESEARCHERS; RIGHT: BETTMANN/CORBIS

June 8, 1976. Lost during long, strange trip.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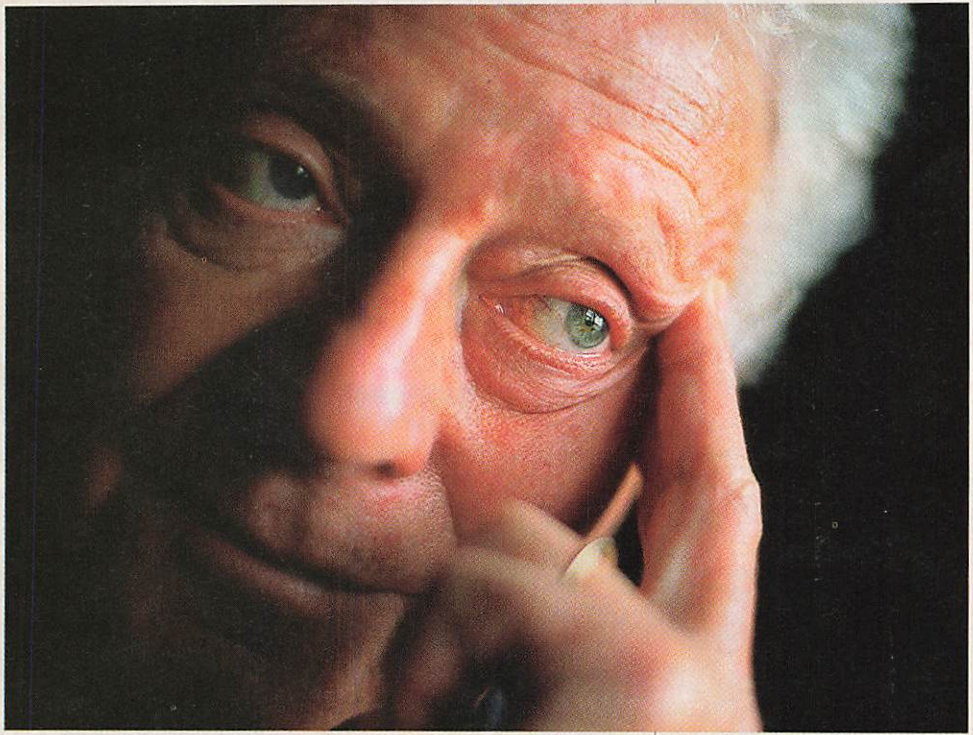

HE SWEATS THE SMALL STUFF

Leon Lederman has been at the center of many of the biggest discoveries in particle physics, including the discovery of two key subatomic particles: the bottom quark and the wraithlike muon neutrino. The latter find earned him the 1988 Nobel prize in physics, shared with Jack Steinberger and Melvin Schwartz. From 1979 to 1989 Lederman ran the Fermi National Accelerator Laboratory in Chicago. These days, as director emeritus of the lab, he devotes most of his time to improving science education in public schools. From his vacation home in Idaho's Grand Teton Mountains, Lederman spoke with *Discover* Associate Editor Kathy A. Svitil.

What is the significance of the work that won you the Nobel prize?

The muon neutrino dictated the organization of all the subatomic particles. Now we know there are three kinds of neutrinos [the third was discovered in July at Fermilab], which tells us there are three generations of particles. These particles, plus the forces that govern their behavior, interact to make all the stuff around us.

What is the biggest unanswered question in physics?

Right now we have a dozen fundamental particles with seemingly random masses. We need a theory of where mass comes from. One possible solution is the Higgs field, a hypothesized force that has the curious property of making some particles light and others heavy. If this view is correct, there is really only one particle, but because we are looking at it through this crazy Higgs field, it looks like a dozen different ones. If we can understand the Higgs field, we can get behind it and see the glorious, pristine simplification of the theory. Then all of physics can fit on the front of a T-shirt: "One particle, one force."

When will we know?

The Large Hadron Collider in Europe, which will be completed around 2006, should be able to test the theory. Even before that, our new machine at Fermilab will open up the search.

Will time travel or teleportation ever become a reality?

There are some weird effects that come out of Einstein's general relativity—wormholes and other *Star Trek* stuff. You can't prove it's impossible, just like you can't prove the nonexistence of God. It looks to me rather bizarre. I'd be worried about "beaming up," because if you make the tiniest error in reconstructing the DNA you might appear as a cockroach.

What about interstellar travel?

As long as you stay below the velocity of light, it is possible. But you'd need a lot of money and a motivation stronger than, say, the motivation for the space station—of which there's almost none, from the point of view of science. Sending people to Mars looks more exciting to me, because it's a grand adventure that's close to being doable right now.

THEY INVENTED IT WHEN?

THE LOCK AND KEY

One of the earliest types of locks, first found in the Near East and dating from about 2000 B.C., was little more than a wooden bolt with some holes drilled into it. When the bolt slid into place, pins on the door dropped into the holes and held it in place; the key was another piece of wood with the same pattern of pegs, which lifted the pins when inserted. The technology didn't improve much until 1778, when Robert Barron conceived of the lever-tumbler lock. A series of levers in the lock had holes at varying heights. Only a key with the right pattern of ridges could line up all the levers and allow the bolt to move, but the lock was easy to pick. In 1784, Joseph Bramah invented a nearly unpickable device, but it was so intricate it could not be mass-produced. Linus Yale Jr. finally hit on a winning combination when he patented his pin-tumbler lock in 1861 and 1865. Like the ancient Middle Eastern lock, his lock uses a series of pins, but it contains them within a cylinder held in place by spring-loaded driver pins. When the key is fully inserted, serrations on the top edge lift all the pins to the correct height and let the cylinder turn. A groove cut into the side permits more kinds of keys, further enhancing security. Next up: computers that read fingerprints or iris patterns will act as "smart keys," opening locks only for authorized individuals. —*Fenella Saunders*

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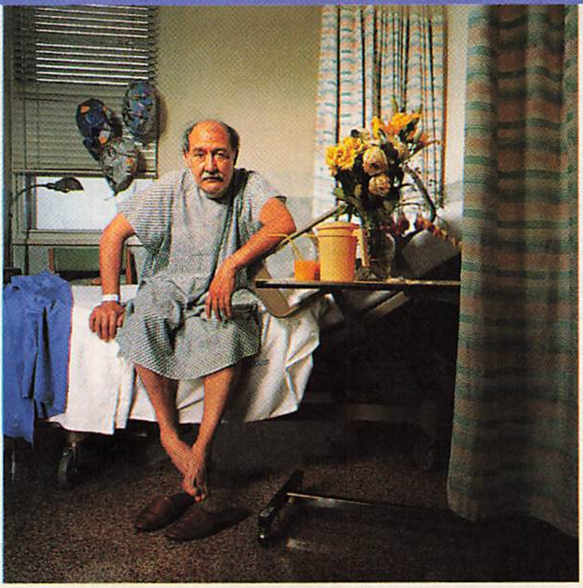

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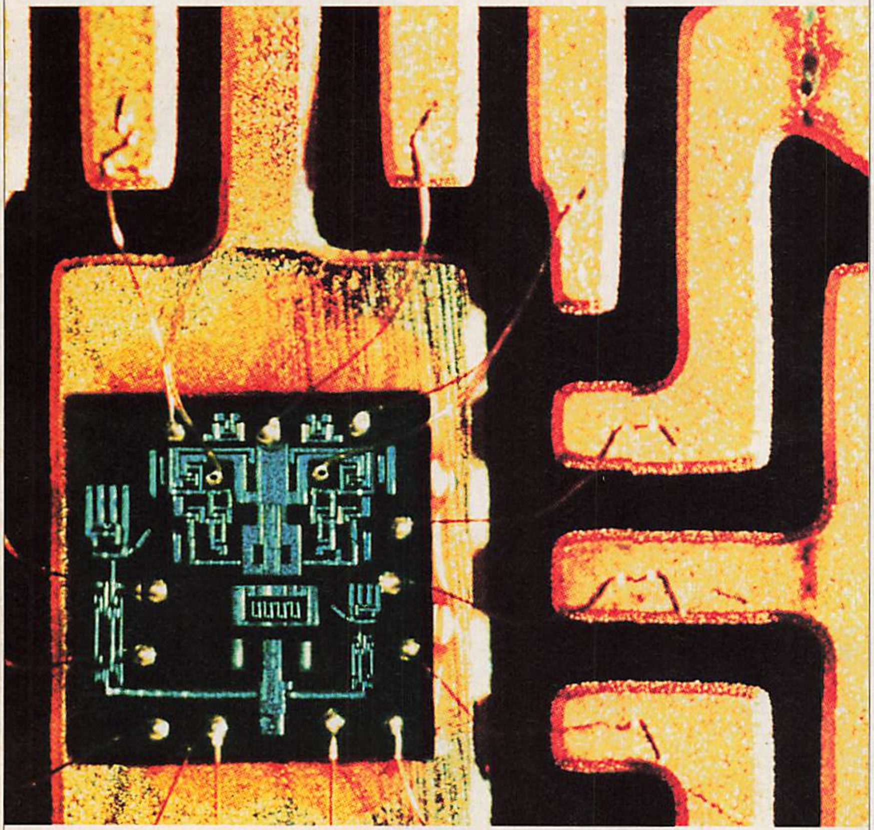


Neurocomputers

What's beyond silicon and fiber optics? Would you believe microprocessors with living brain tissue?

AS EVERYONE WHO BUYS A COMPUTER LEARNS, ELECTRICAL ENGINEERS somehow manage to keep creating smaller and smaller microprocessors that double the speed of PCs about every 18 months. Keeping perspective can be difficult, but consider that the power of the first room-sized mainframe computer of 36 years ago is now dwarfed by any run-of-the-mill laptop. So what's wrong with this picture? Biomedical engineer William Ditto points out that today's processors may be a lot faster, but they're not a bit smarter than they were 40 years ago.

The dream of artificial intelligence that would allow a computer to learn, and thus get really smart, has proven to be something of a nightmare so far. That failure has led Ditto and his team of researchers at the Georgia Institute of Technology and Emory University to look beyond silicon and even beyond light chips. "First there were beads on an abacus, then vacuum tubes and integrated circuits," says Ditto. "Now we can use living tissue."

These days his neurons of choice are taken from leeches because "they are really big and easy to use." And they learn quickly. Not long ago, Ditto and his team coached two living leech neurons to perform very simple addition—a humble beginning, but one that might lead to harnessing millions of similar neurons into a computer that solves problems using the nonlinear pattern-finding logic of the human brain. Although seemingly far-fetched, Ditto's belief that neurons could be the basis of the next great computer wave can be infectious. "Bill is our spiritual leader," says Georgia Tech neuroengineer and collaborator Steve DeWeerth.

Brains derive awesome problem-solving abilities from two characteristics of their individual cells. First, a neuron can be in any one of thousands of different states, allowing it to store more information than a transistor, which has only two states, on and off. Second, neurons can choose which other neurons to talk to by rearranging their own synaptic connections. Neurobiologists call this self-organization.

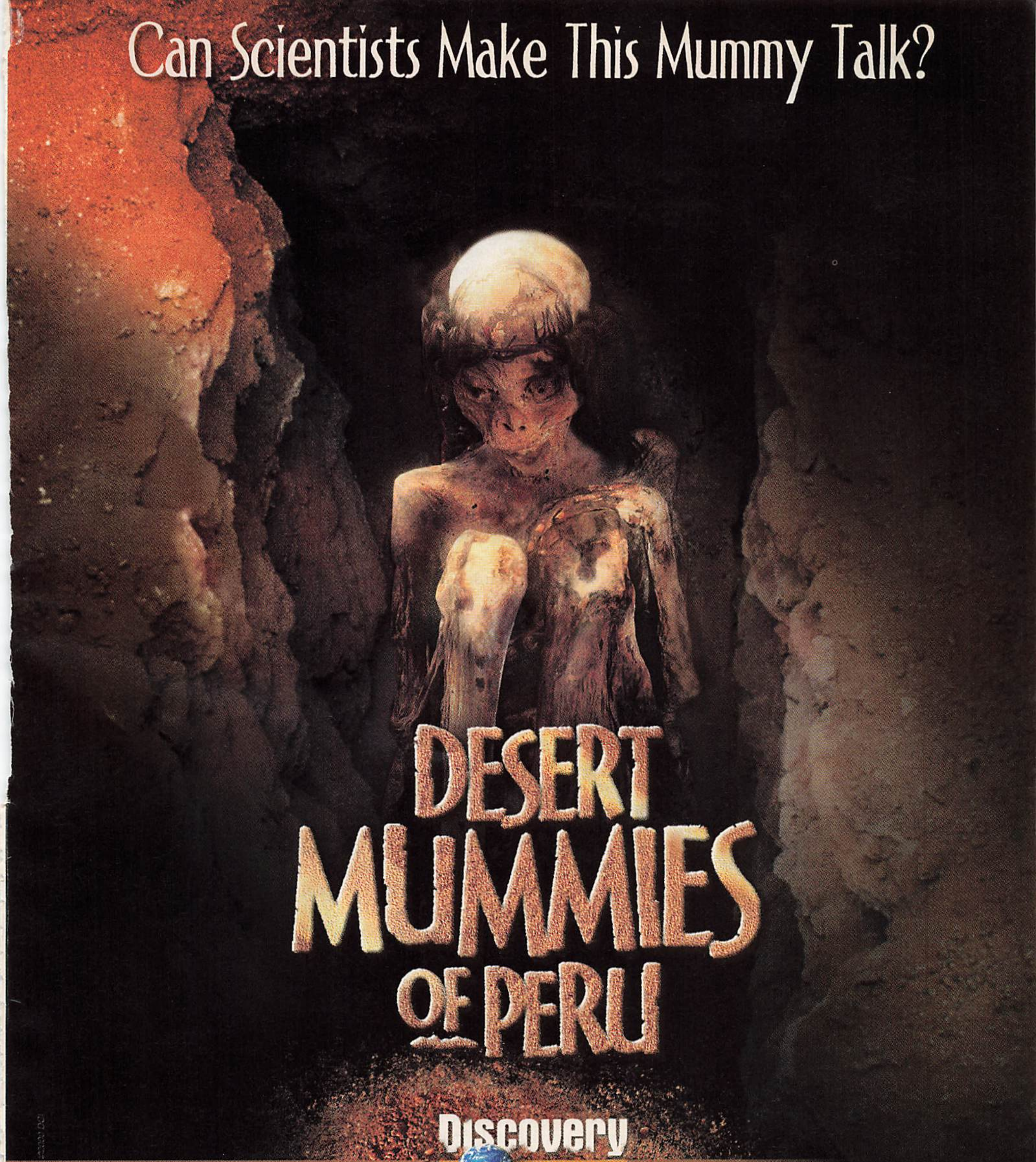
Although scientists have developed software that attempts to mimic the brain's learning process using only the yes-no binary logic of digital computers, all the connections in a personal computer are wired back at the factory. Breaking a single one of these connections usually crashes the computer.

That is not a problem for a neurocomputer. "Dynamic chaotic systems like these naturally self-organize," Ditto says. Take the human heart. An isolated heart neuron simply sparks chaotically, without apparent intelligence. But when it is a part of the neuronal network in a living heart, it synchronizes with all the other neurons to create a steady heartbeat. A neurocomputer might work in a similar way. If a computer programmer could pose a problem to a collection of neurons, such as "create a regular heartbeat," the neurons might then figure out through trial and error how to rewire their own circuits to produce a steady rhythmic beat.

Of course, figuring out how to pose complex questions to neurons is a monumental programming challenge.

Your computer's DVD player may be able to show a full-length motion picture, but it is a long way from being able to watch and respond to one like a human. The neurons linking the human retina to the brain process images more than a million times faster than the fastest computer.

PHOTO ILLUSTRATION BY PETER GOTT (CHIP PHOTOGRAPH BY H. ARMSTRONG ROBERTS)



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Neurons speak a terrifically complicated language. Each "word" in the neuron lexicon is a repeatable pattern of electrical impulses. And when neurons talk to each other, these electric words are transmitted across synapses, electrical connections that link neurons into a network. Each synaptic connection can have as many as 200,000 channels, and every channel carries information about a different aspect of cell life, a bit like the way your television simultaneously receives cable programming on different channels.

Until a few years ago, untangling and interpreting so many intercellular conversations seemed impossible: Imagine trying to translate every word said by news anchors broadcasting entirely in Latin over 200,000 channels of cable television. Ironically, it's the advancing power of the modern digital computer that has made such problems solvable. Using the speed of microprocessors to crunch differential equations, Eve Marder, a neurobiologist at Brandeis University, has developed a computer program called the dynamic clamp that can translate neuron-speak in real time.

"WE DON'T KNOW HOW A BIOLOGICAL SYSTEM SELF-ORGANIZES," SAYS GEORGIA INSTITUTE OF TECHNOLOGY NEURO-ENGINEER STEVE DEWEERTH. "BUT WE MIGHT NOT HAVE TO UNDERSTAND IT TO EXPLOIT IT"

Electrical impulses are transmitted to the computer through probes inserted into the neuron. The dynamic clamp "reads the cell's voltage, then uses the voltage and an equation that calculates the current that would flow at that voltage," says Marder. Then it computes and generates a response that is sent back though the probe. By controlling the strength of the reply pulse, the program mimics a neuron conduction channel, and the neuron reacts as if it were communicating with another neuron, not a computer.

Biomedical technicians extract nerve cells from a leech for use in the first working neurocomputer.

GARY MEEK/GEORGIA TECH

Ditto's team uses the dynamic clamp in the opposite way: to give orders. The computer sends a stimulating electric signal to the neuron, thereby instructing the cell which state to adopt. To add a pair of numbers, for example, Ditto "tells" two cells to go into states corresponding to two numbers. The two cells are then electrically linked through the computer and told to "add." They reply with the answer. Even Ditto admits that this is a very simple success. "We have loaded the deck," he says. "We know the information is there."

Next the team wants to build a neurocomputer sophisticated enough to learn tasks, such as how to move the legs of a robot walking over a boulder-strewn landscape or to recognize abstract spatial patterns, including stick-figure drawings of people. Either accomplishment will be difficult to pull off. "Compared to learning how to walk, calculus is easy," DeWeerth says. And harder problems require more neurons. "We need hundreds of thousands of neurons to solve these complicated tasks," he says. Which presents a major challenge: "How do we program them all?"

In one sense, it should be easy. "Very simple rules can generate complex behavior," Ditto says. Forager ants, for example, create elaborate civilizations out of a mere handful of very simple rules. But how do you figure out the fundamental set of simple rules?

It is a question that may never have to be answered. "We don't know how a biological system self-organizes," DeWeerth says, "but we might not have to understand it to exploit it." Instead of linking every neuron via computer, the team plans to connect a computer to a small number of neurons and allow them to communicate with a much larger network of neurons. The computer interface will stimulate the neurocomputer in the same way that our eyes, ears, noses, and hands provide sensory stimulation to our brains. By sending information and feedback through the interface, "we will teach the neurons to make the right connections themselves," DeWeerth says.

Constant repetition may be the key. "The brain adapts continuously, so we keep getting better at tasks that we repeat," DeWeerth says. For example, when a novice tennis player lofts a ball above his head and hits it, the brain gradually learns to coordinate the muscles needed to serve the ball. But teaching neurons takes time. Just imagine how many serves Pete Sampras had to hit before he won at Wimbledon.

Fortunately, neurons love to practice, so Ditto's team is working hard to get them started. "We are now gearing up to use two- and three-dimensional pieces of neural tissue for computing," he says. Within seven years, he hopes to teach a millimeter-sized cube of neurons to do arithmetic and recognize patterns. Because it is impossible to insert a computer moderator between all the different nerve layers, this will be the first attempt at letting the neurons make their own interconnections. Ditto acknowledges that "there are still lots of engineering headaches. But once you get the neurons started, you almost can't stop them from computing."

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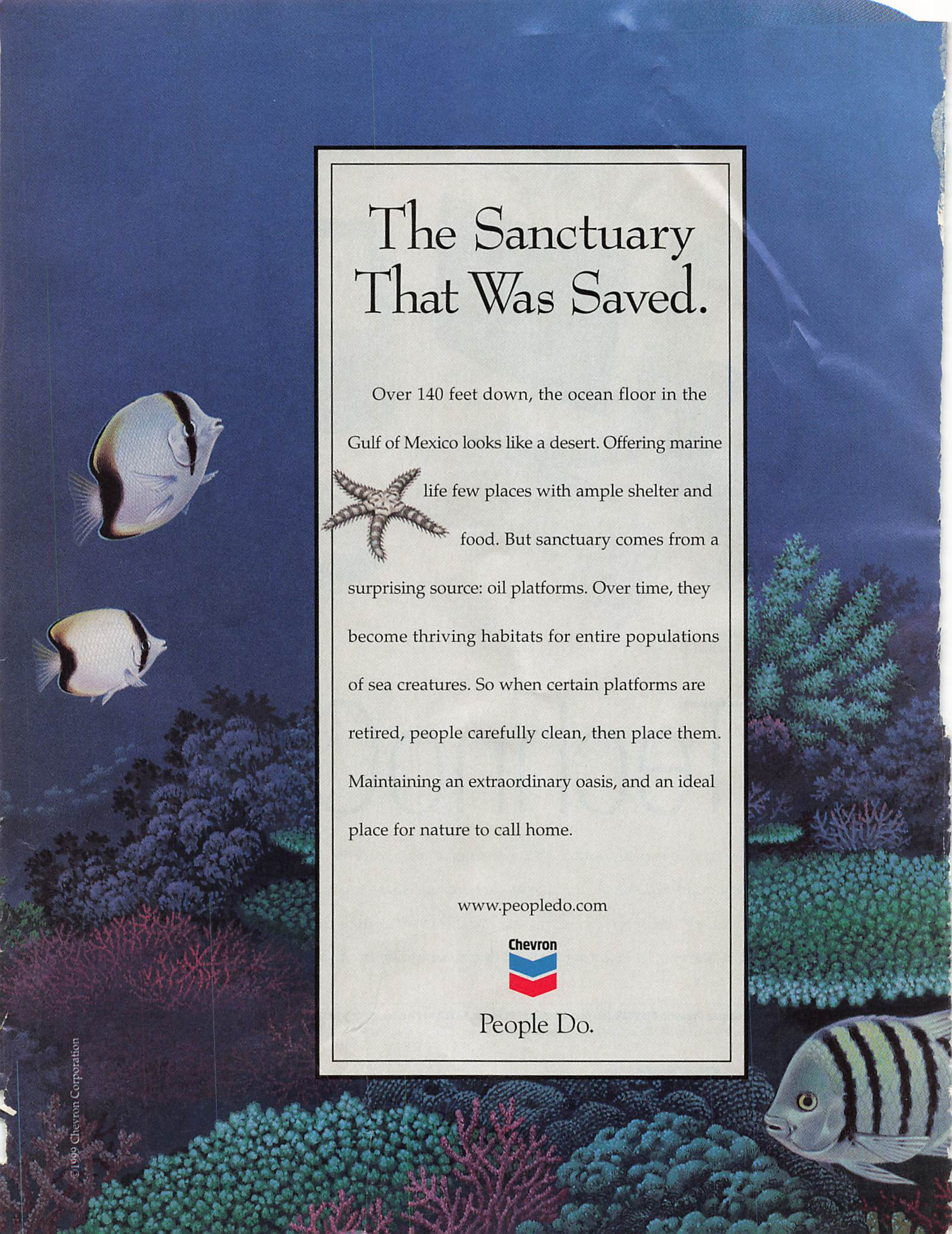

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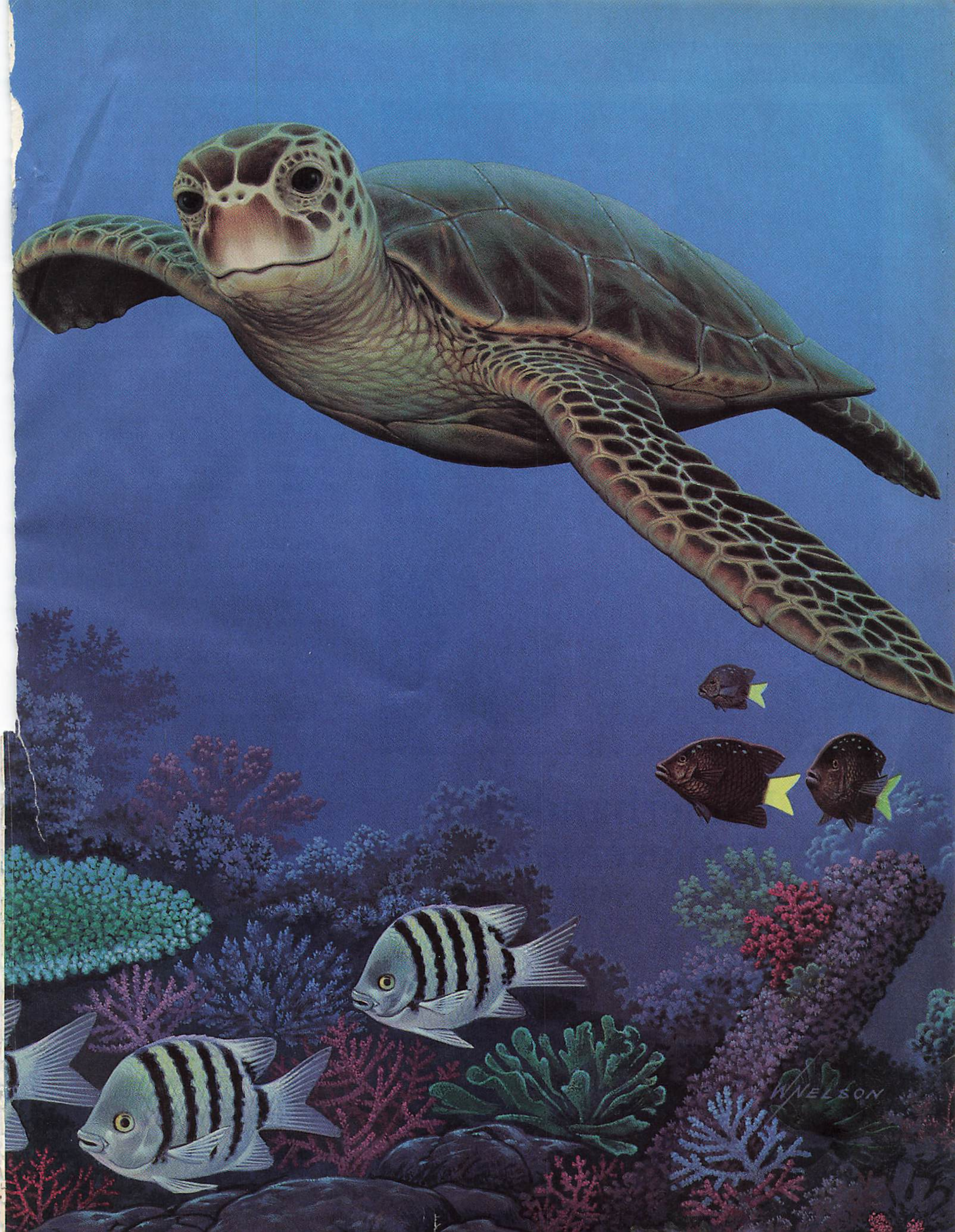
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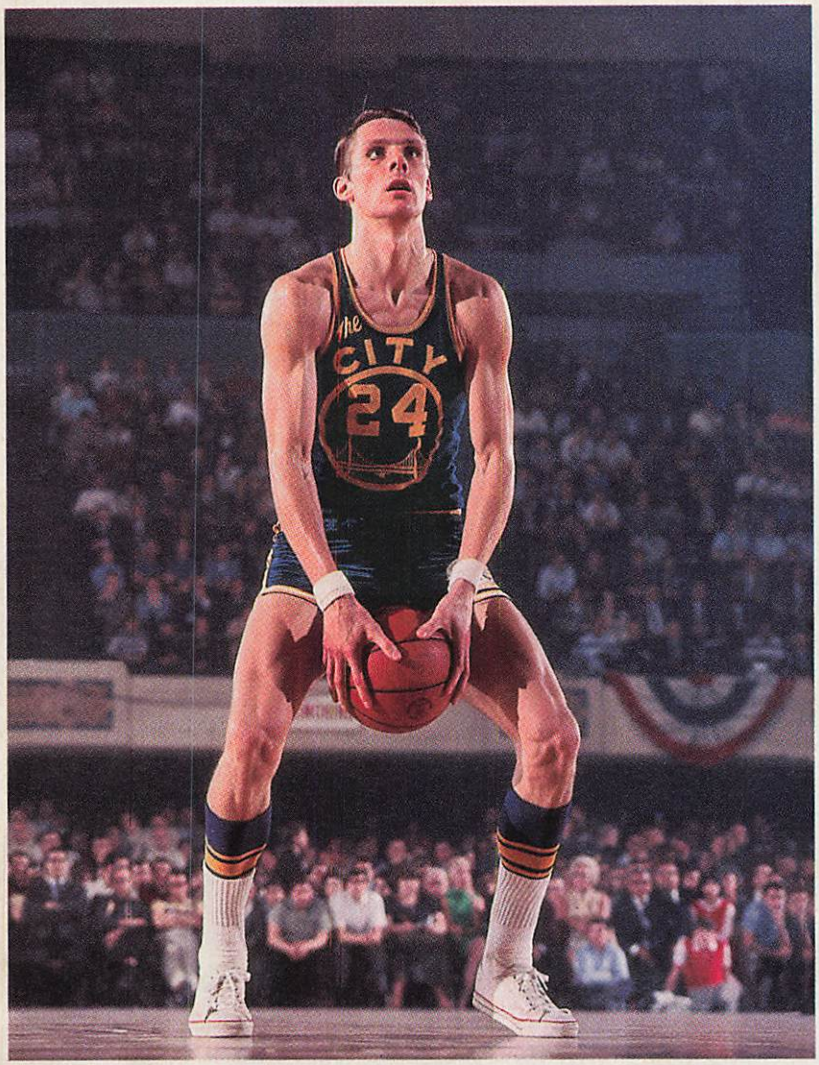
THE PHYSICS OF FOUL SHOTS

by curtis rist



Underhanded Achievement

Why everyone in the NBA ought to be using a granny shot from the foul line

AS A BOY IN ELIZABETH, NEW JERSEY, IN THE 1950S, BASKETBALL legend Rick Barry got some painful coaching lessons from his father, a semipro. While the youngster's friends liked to shoot their foul shots, or "free throws," in the respectable overhand style, the old man wanted Barry to toss them just as he did—underhand. "That's the way little kids shoot, and it didn't help that everybody calls it the 'granny shot,'" Barry says. "I didn't want any part of it, but my father drove me nuts until I tried it. And amazingly, it worked." Barry's average from the free-throw line bounced from 70 to 80 percent and kept on climbing when he became a pro. "Nobody ever teased me, but then it's hard to tease somebody when the ball keeps going in."

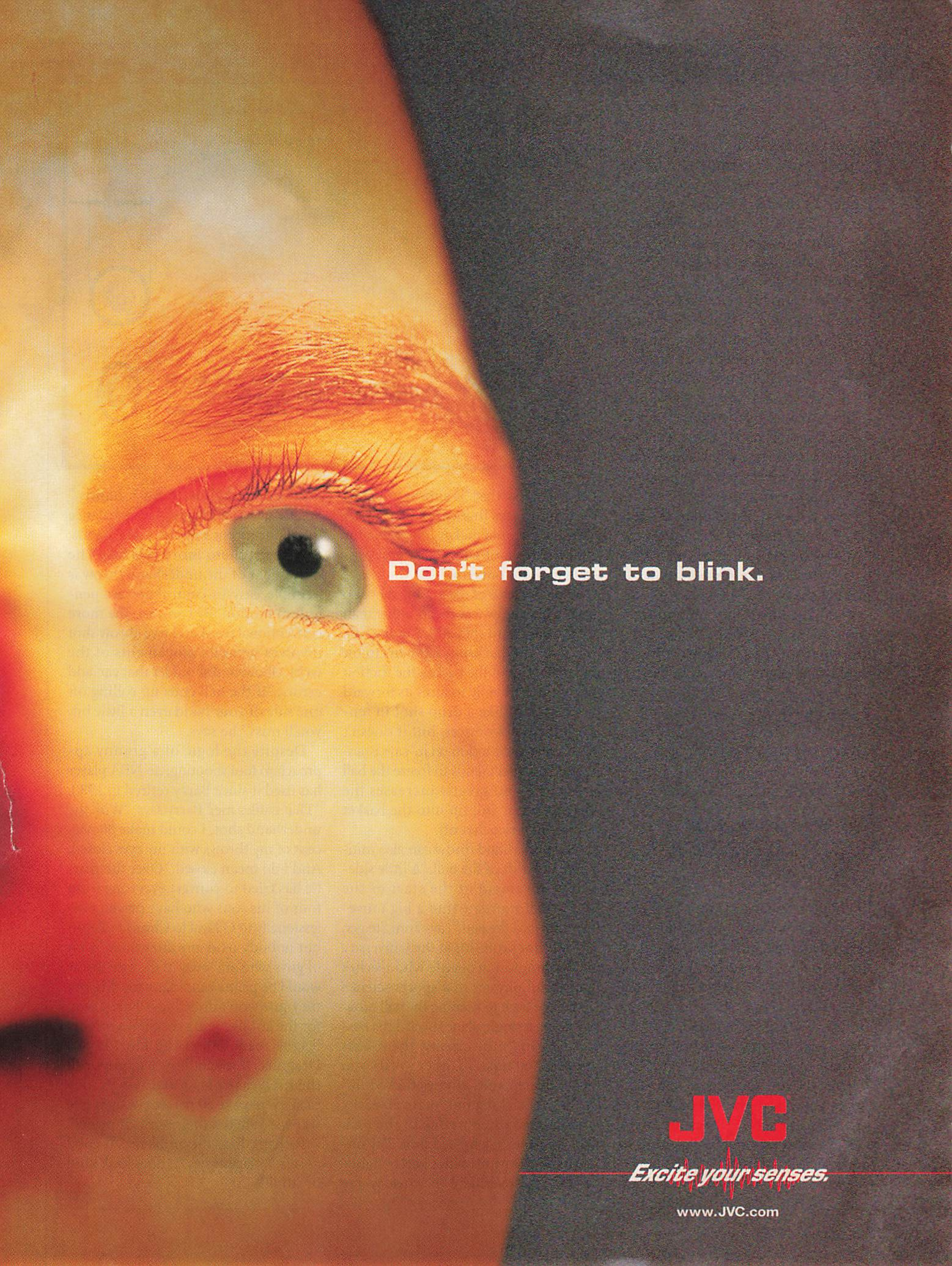
Judging by mechanics alone, this should be the case with just about every foul shot. "There's nothing simpler in basketball, because you can take all the time you want to make it, and there's nobody waving their arms in front of you trying to block you," says Peter Brancazio, a physics professor emeritus from Brooklyn College and author of *SportsScience*. "It's like bowling. You do exactly the same thing over and over and over again." Yet while Barry can easily sink nine out of 10 shots, others fall far short. The late Wilt Chamberlain, for instance, could shoot a basket from just about anywhere on the court—except when he toed up to the line 15 feet from the hoop. There, the legendary "Big Dipper" sank barely five out of 10 shots, although he got plenty of practice: 11,862 attempted free throws, a National Basketball Association record that still stands.

Left: Rick Barry says any pro should be able to make 70 percent of his foul shots: "Same size ball, same shot, same distance, basket's the same size, same height. How can you not make seven out of 10?"

Sports columnists gripe about the bad free-throw techniques of modern players like Shaquille O'Neal, but no one has suffered more public humiliation at the free-throw line than the Knicks' Chris Dudley. One year, he made only three out of every 10 shots, and last season, when he managed to sink two free throws in a row during post-season play-offs, he made headlines ("Chris No Dud at Foul Line!" screamed the New York *Daily News*). "I'm convinced that from a physics →

Mark Price, who spent nine of 12 pro seasons with the Cleveland Cavaliers, holds the NBA record for the best career in-season foul shooting percentage. More than nine out of every 10 of his 15-footers dropped, giving him a .907 average. He also made 202 of 214 foul shots in play-offs.

WALTER IOOSS, JR./NBA PHOTOS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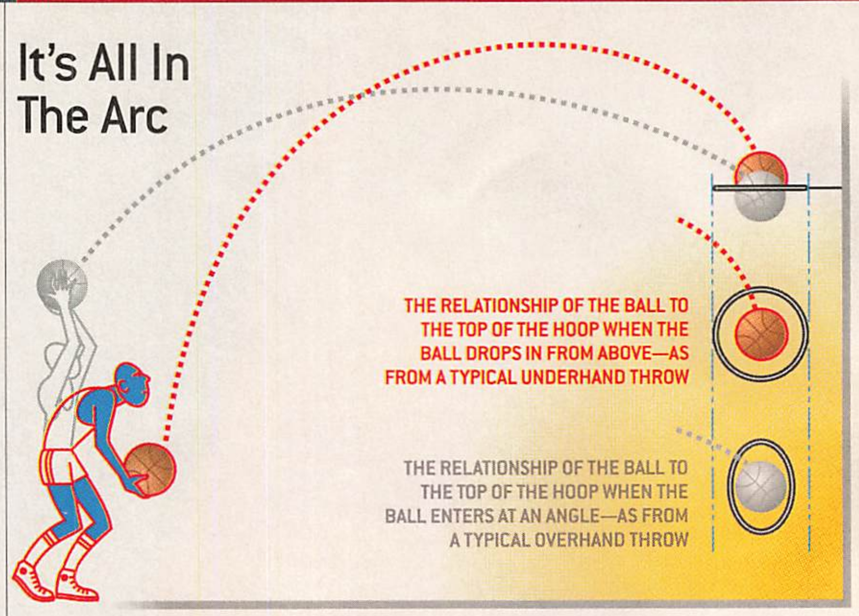
→ standpoint, if everyone learned to throw underhand you'd see these statistics rise dramatically," says Brancazio.

The key to a successful foul shot lies in the arc of the ball—in general, the higher the better. While an official-sized basket is 18 inches in diameter, the basketball itself is only about 9.5 inches, which gives a margin of 8.5 inches. But when the ball is thrown nearly straight at the basket—in the style of Shaquille O'Neal—the margin disappears because the rim of the basket, from the perspective of the ball, resembles a tight ellipse. "That's why these guys miss so much," says Brancazio. "Because of the sharp angle of the typical overhand throw, there ends up being a much smaller window for the ball to go in." If the ball comes down at the basket from a steeper angle—the way it does if tossed up in the high arc characteristic of an underhand throw—the margin reappears. "That means there's a far greater chance of making the basket," he says.

"THE SHORTER YOU ARE, THE STEEPER THE ANGLE HAS TO GET TO GIVE YOU THE BEST CHANCE OF MAKING THE SHOT"

Using lots of trigonometry, Brancazio calculated the optimal angle of the arc from the free-throw line. If tossed at 32 degrees or less, the ball will likely hit the back of the rim. "That doesn't mean it won't go in, but it will certainly bounce off the metal and reduce the chance of success," he says. At angles greater than that, the ball has a chance of making a nice *swish*. The optimum angle, he calculated, is 45 degrees—plus half the angle from the top of the player's hand to the rim. "The shorter you are, the steeper that angle has to get to give you the best chance of making the shot," he says. Of course, lobbing a ball very high so that it comes down nearly straight into the basket would be the most efficient technique, but a shot like that "is almost impossible to aim," says Brancazio. Instead, he says, his formula makes it possible for a player to shoot with the largest possible margin for error.

It's All In The Arc



THE RELATIONSHIP OF THE BALL TO THE TOP OF THE HOOP WHEN THE BALL DROPS IN FROM ABOVE—AS FROM A TYPICAL UNDERHAND THROW

THE RELATIONSHIP OF THE BALL TO THE TOP OF THE HOOP WHEN THE BALL ENTERS AT AN ANGLE—AS FROM A TYPICAL OVERHAND THROW

Another factor of the granny shot also helps a free throw win cheers rather than jeers: a backward spin added to the ball. If a ball with backspin happens to hit the metal rim of the basket, the friction of contact suddenly reduces its forward velocity. "It's like a drop shot in tennis—the ball bounces, but it doesn't have a forward motion on it," says Brancazio. This effect tends to freeze the ball at the rim and greatly increases the chance that it will tip into the basket rather than ricochet off.

The underhand throw can also minimize the drift of the ball. "A little sideward movement at the start of the throw will translate into a big movement toward the end," says Tom Steiger, an assistant professor at the University of Washington in Seattle who teaches basketball physics in a sports science class. The trick to keeping the ball moving along a single plane toward the basket lies in "minimizing the *x*-axis motion," he says. "In other words, you have to keep your elbows tucked in." If they're sticking out, that can easily add an unwanted nudge to the ball, which results in a missed shot. The underhand throw provides better stability than the overhand "because you're holding the ball with both hands," Steiger says. This helps players balance the subtle motor muscles in the hands, and keeps them more relaxed. The movement of the underhand throw is a simple, easy-to-control upward pendulum motion. By contrast, the more conventional overhand free-throw shot involves separate movements of the wrist, elbow, and shoulder that can add errors. "If the ball ends up rolling off one side of your hand even a little bit, you'll miss," he says.

Despite the logic of a granny approach to foul shooting, no NBA player has used it since Barry retired in 1980. "That baffles me," Barry says. "With the underhand shot, I could make 80 percent of my throws with my eyes closed. And I do mean closed." Over the years he has tried to convert everyone from four of his sons who have played professionally to O'Neal to Chris Dudley—but nobody paid any attention. "A lot of guys who are lousy at the free throw would be prime candidates for this, but they just won't do it," says Barry, who for the last five years coached a minor-league team called the Florida Sea Dragons. "I mean, how can guys call themselves professionals when they can't even make 60 percent of their free throws? Where's their sense of pride?"

Perhaps that's the problem. "As good as it is," Steiger says, "it does look kind of stupid." ☒

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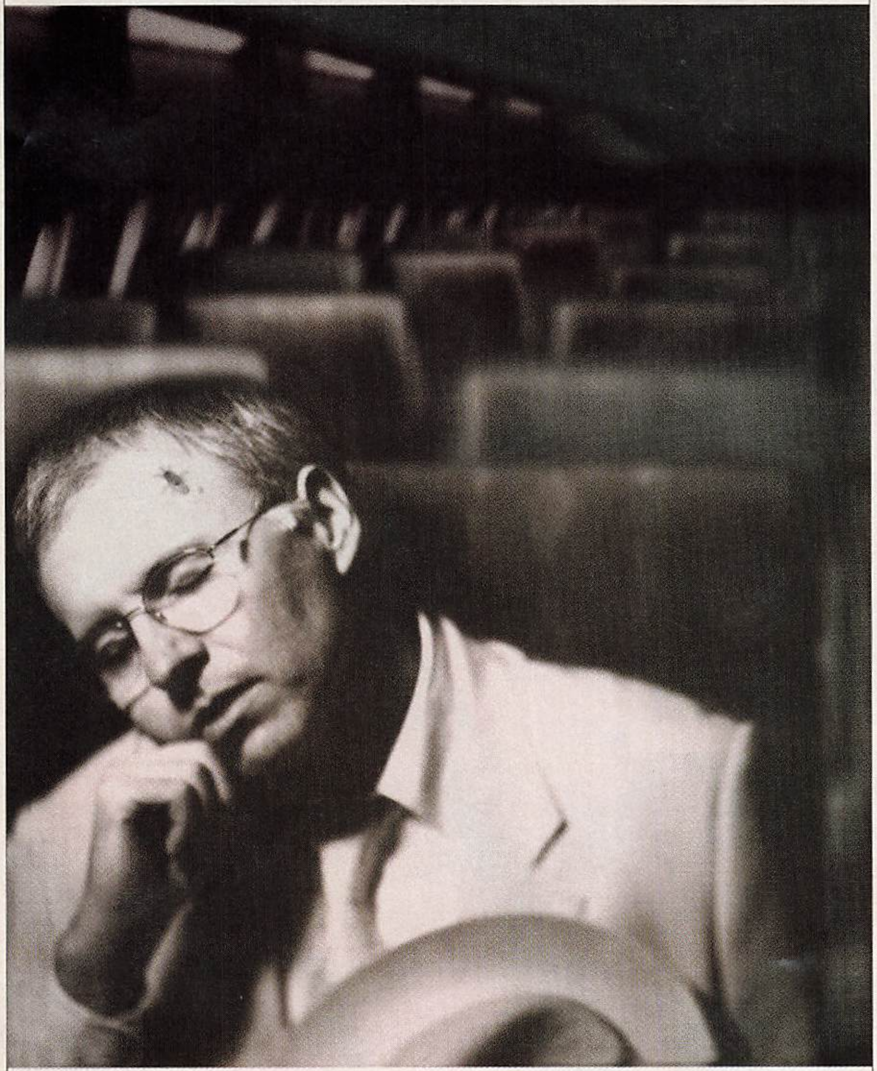
by claire panosian dunavan



Much Too Tired

Mr. Post's escalating fever after a monthlong trip into the bush was not a good sign

CHRISTOPHER POST WAS NOT YET HOME WHEN HE NOTICED THE crimson spot, roughly nickel-sized, on his left biceps. Returning from the trip of a lifetime, a monthlong safari in Africa, he was tired, achy, and hot. Maybe it's eczema, the 50-year-old stockbroker reasoned. He'd be better in a couple of days.

But a few days later, Mr. Post was worse, with a higher fever. The spot on his arm was bigger. His internist was out of town, so he drove to a nearby hospital.

"Did you use malaria pills in Africa?" asked the emergency-room physician.

"Yes, and I also got shots before leaving," Mr. Post said. For the trek to Tanzania and Rwanda, he had prepared by the book: yellow fever and typhoid vaccines, a quinine-type drug to stave off malaria, and a stash of diarrhea pills.

"I'm not sure about that bug bite," the doctor mused, "but your fever is straight from the textbooks. Sounds like malaria to me. We'll start with a blood exam."

An hour later, he returned with microscope slides.

"Mr. Post," he said, looking grave, "your problem is not what I thought. Here are your blood smears. Our hospital is not prepared to take care of you. They're expecting you at the university hospital as soon as you can get there."

Andy Peters was the internal medicine resident on duty at the university hospital ER that day. He liked figuring out infectious diseases—the more exotic, the better. Andy's jaw fell as he scanned through Mr. Post's blood smears. He had expected to see the delicate rings of the malaria parasite within red blood cells. Instead he saw wavy, whip-tailed creatures swimming free like eels. By microscopic standards, they were big eels—twice as long as the patient's blood cells.

Andy consulted descriptions of another blood-borne parasite from Africa: *Trypanosoma brucei.* Bingo. Perfect match.

He headed to the patient's room, introduced himself, and explained his discovery: sleeping sickness.

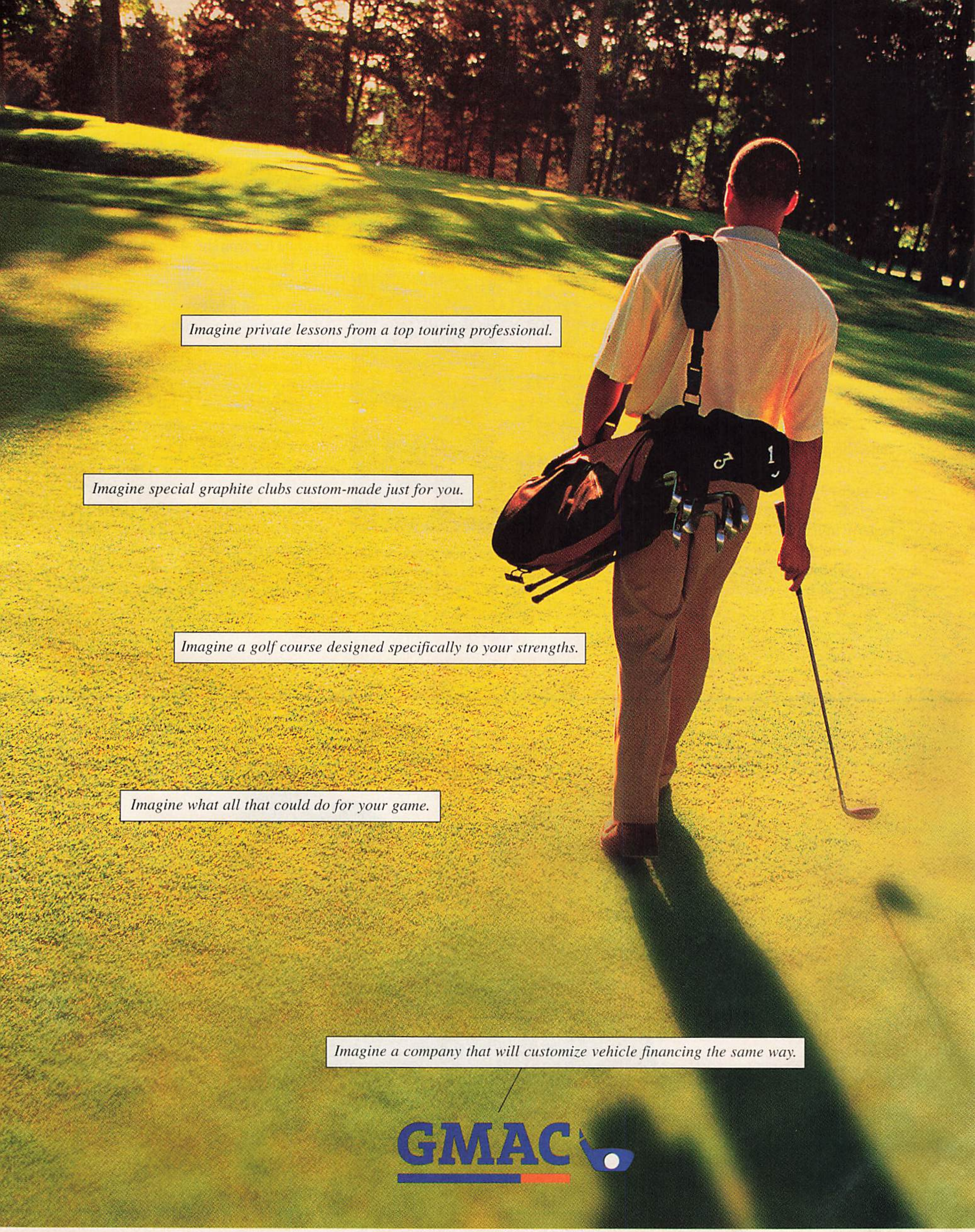
That's when Christopher Post decided to make out his will.

Swift death is common among victims of East African trypanosomiasis, the variety infecting Mr. Post. In 1906, it killed at least half of Uganda's 6 million inhabitants. West African, or Gambian, trypanosomiasis is the more insidious, classic sleeping sickness, causing creeping inflammation of the brain that over a period from months to years gives rise to seizures, psychosis, stupor, coma, and death.

But whatever its geographic subtype, the insect vector of African →

Trypanosomiasis infects an estimated 300,000 Africans. In some villages, half of the residents may be infected. And in the Democratic Republic of the Congo, the disease is thought to cause as many deaths as AIDS. Because of the parasite, vast regions of Africa are unsettled.

PHOTO ILLUSTRATION BY JEFF SCIORTINO; IMAGING BY TAKESSI GOMEZ/BOHEMIAN COMMUNICATIONS; TSETSE FLY BY ARCHIVE PHOTOS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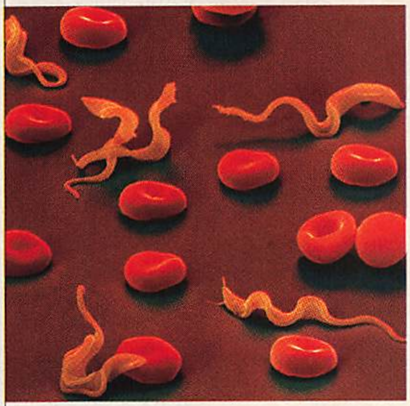
→ trypanosomiasis is always the same: the tsetse fly. Twice as big as a housefly, with predatory mouth parts and scissorlike wings, it breeds in dark, moist niches of sub-Saharan forests and thickets. East African tsetse flies acquire trypanosomes from the blood of infected animals, typically savanna-dwelling bushbucks, or infected humans. West African tsetses tend to acquire the parasite by feeding off infected humans. In both locales, parasites multiply in the fly's stomach, then migrate to salivary glands. At that point, one bite is all it takes to launch a new infection in another animal or human.

Weeks into his illness, Mr. Post recalled brushing off some "really big insects" in Africa. However, at the time, he had no idea they were tsetse flies. Nor in his wildest savanna dreams could he have imagined the battles these parasites would wage in his body.

Trypanosomes have a canny way of dealing with the body's immune defenses. As early as 1910, researchers noticed wave after wave of parasites in the blood of sleeping sickness victims. Today we know that each wave represents a new generation with altered surface proteins. This new coat triggers a fresh volley of host antibodies. The antibodies work at first, but ultimately they fail in the face of yet another battalion of reconfigured parasites.



***Trypanosoma brucei*, the parasite that causes sleeping sickness, is about twice as long as a red blood cell.**

OLIVER MECKES/PHOTO RESEARCHERS

By the time Mr. Post reached the university hospital, the battle in his bloodstream had been under way for weeks. Not only had the parasites glutted his bloodstream, but he also was taking friendly fire from his own immune system. He had severe anemia, a dangerously low platelet count, malfunctioning kidneys, and a baggy, inflamed heart, all due to his own antibodies attacking his own tissues.

The most dreaded complication of sleeping sickness is brain infection. A test of Mr. Post's spinal fluid would show if the parasites had infiltrated his central nervous system. If we found them there, our only hope for ridding Mr. Post of the infection was melarsoprol, an arsenic-based parasite poison that also kills about six percent of patients.

We have very few treatment options for sleeping sickness, and all of them are toxic. To pick the right drug, we

THE DAYTIME, NON-DROWSY, CONGESTED-STUFFY HEAD, SORE THROAT, COUGHING,

must identify the particular strain of the parasite and its stage of infection. Needless to say, when I got called about Mr. Post, I was concerned. I am the local tropical medicine expert, but I'm not above asking for help.

My first call went to the Centers for Disease Control in Atlanta. They operate a 24-hour hotline for crises involving parasites like *Trypanosoma brucei.* After hearing that Mr. Post's spinal fluid was clean, the doctor on call recommended suramin, another toxic remedy, used since the 1920s. The only problem was that the CDC has the only supply of suramin in the United States. That meant it could not reach Mr. Post until at least the following day.

Could we afford to wait? Over the past 12 hours, his fever had shot even higher, and his follow-up blood smears showed wall-to-wall parasites. In desperation, we gambled on pentamidine, an antiparasitic drug we had in the hospital pharmacy. The following afternoon we started suramin.

The next few days were rocky. Within hours of treatment, the drugs killed the parasites, spilling their remains into the bloodstream. That put the immune system into overdrive. Mr. Post's blood count plummeted, his heart and kidneys worsened, and most telling of all, the bite on his arm grew huge, its borders jagged and magenta. Our dermatologist hadn't seen anything like it.

But two weeks later, the victim was the victor. Just about everything we take for granted in modern health care—technology, teamwork, and drugs—contributed to beating the infection.

Today, Mr. Post and I have a special bond. After all, I'm not likely to see another case like his soon. Prior to his arrival at the emergency room, only a handful of red-hot sleeping sickness infections had been seen in the United States in a decade. Mr. Post, in turn, gained a perspective on tropical medicine no textbook could ever teach. Compared with that of fellow sufferers, Mr. Post's care was a high-tech luxury and a miracle beyond imagination.

In the land of the tsetse fly, where even the most fundamental health care is scarce, thousands die from sleeping sickness every year. ☒

THE DOCTOR IS IN

Almost 30 years ago, Claire Panosian Dunavan was a medical volunteer in Haiti, where she worked in a hospital without electricity or telephones. "I've been hooked on tropical medicine and international health ever since," she says. Dunavan is a clinical professor of medicine and infectious diseases at the UCLA School of Medicine.

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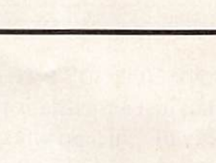

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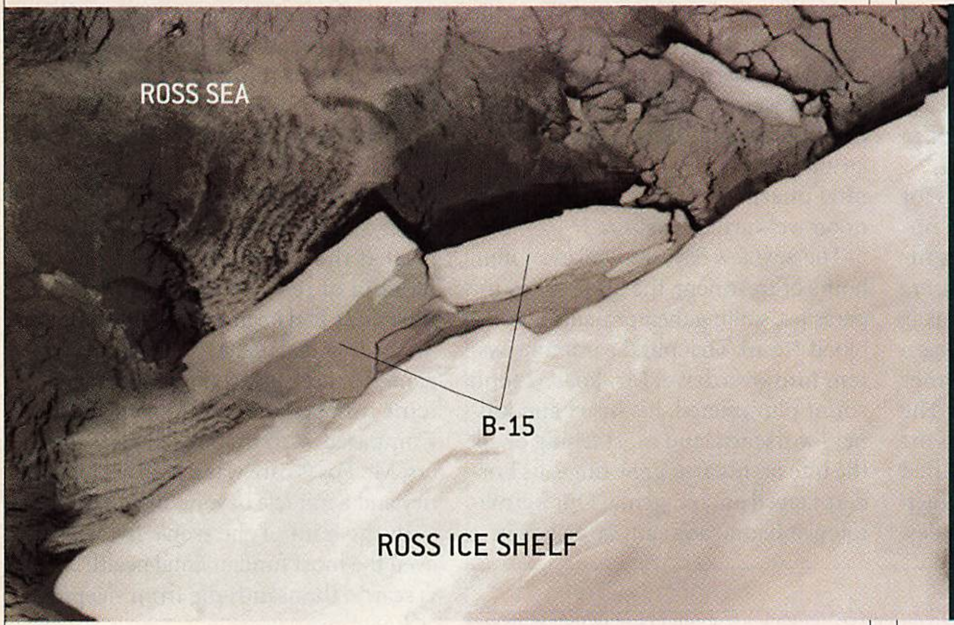

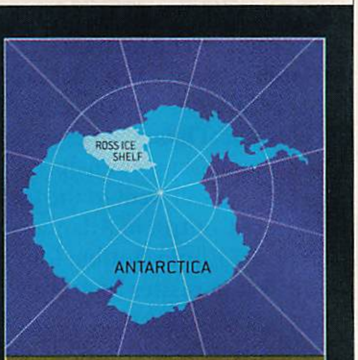

The super-berg B-15—183 miles long and 23 miles wide—broke off the Ross Ice Shelf last March. By May, it had broken into two parts and drifted about 20 miles from shore.

ANTARCTIC METEOROLOGY RESEARCH CENTER

Birth of An Antarctic Super-berg

Whither the biggest iceberg in recorded history?

IF AN ICEBERG BREAKS LOOSE FROM ANTARCTICA AND NOBODY'S THERE to hear it, does it make any sound? That koan is more than just a meditative exercise for Doug MacAyeal, a glaciologist at the University of Chicago who has spent decades pondering the vast Antarctic ice sheets and the huge bergs they spawn. Neither he nor anyone else has ever witnessed firsthand the calving of an Antarctic berg, and the process still mystifies polar experts.

That's because Antarctic icebergs are a world apart from their craggy Arctic kin. While the latter break off in spikes and spires from narrow glacial tongues, Antarctic bergs are flat slabs rent from shelves of fossil snow that stretch hundreds of miles over the coldest water on Earth. They can be thousands of times bigger than boreal bergs, closer to the size of a small state than a large ocean liner. The most enormous Antarctic bergs are rare and elusive, embarking only once every few decades in untraveled seas and rarely straying far from the frozen continent.

So there was much rejoicing among MacAyeal and his associates in March when satellites spotted the largest berg in recorded history separating from the northern edge of the Ross Ice Shelf. The new arrival, dubbed B-15, is the size of Connecticut above water and 10 times bigger below. Melted, it would fill about half of Lake Michigan's basin with 250 trillion gallons of water. MacAyeal was especially jubilant, because he and his collaborators had predicted the parturition of the Ross Sea super-berg years in advance. Just a few days before its calving, he had even reminded a colleague at the National Science Foundation that shipping lanes to the United States' McMurdo Station could be blocked if the giant raft of ice happened to wander westward.

"I knew that berg would be born someday," says MacAyeal. "I had my hand on the kicking stomach of the Antarctic ice sheet."

But even the most doting iceberg obstetrician can't tell exactly when a piece of ice will set out to sea, or where it will go once it has embarked. MacAyeal's prediction is a case in point. In the mid-1980s, working with oceanographer Stan Jacobs at Columbia University's Lamont-Doherty Earth Observatory, he'd compared descriptions of the Ross ice front dating back as far as 1841, when British explorer Sir James Clark Ross first described the "great ice sea barrier." MacAyeal and Jacobs found that the front waxed and waned in cycles. It advanced into the ocean for about 50 years, then dropped back abruptly by about 20 miles before advancing seaward again. They reasoned that the ice-front retreats were the result of massive icebergs breaking off the end of the shelf. In satellite →

Antarctica receives only about a foot of snow each year, some of it crystallizing out of thin, clear air. But its ice sheet, built up over tens of thousands of years, holds around 70 percent of the world's freshwater. In some places, the ice sheet is more than a mile thick.

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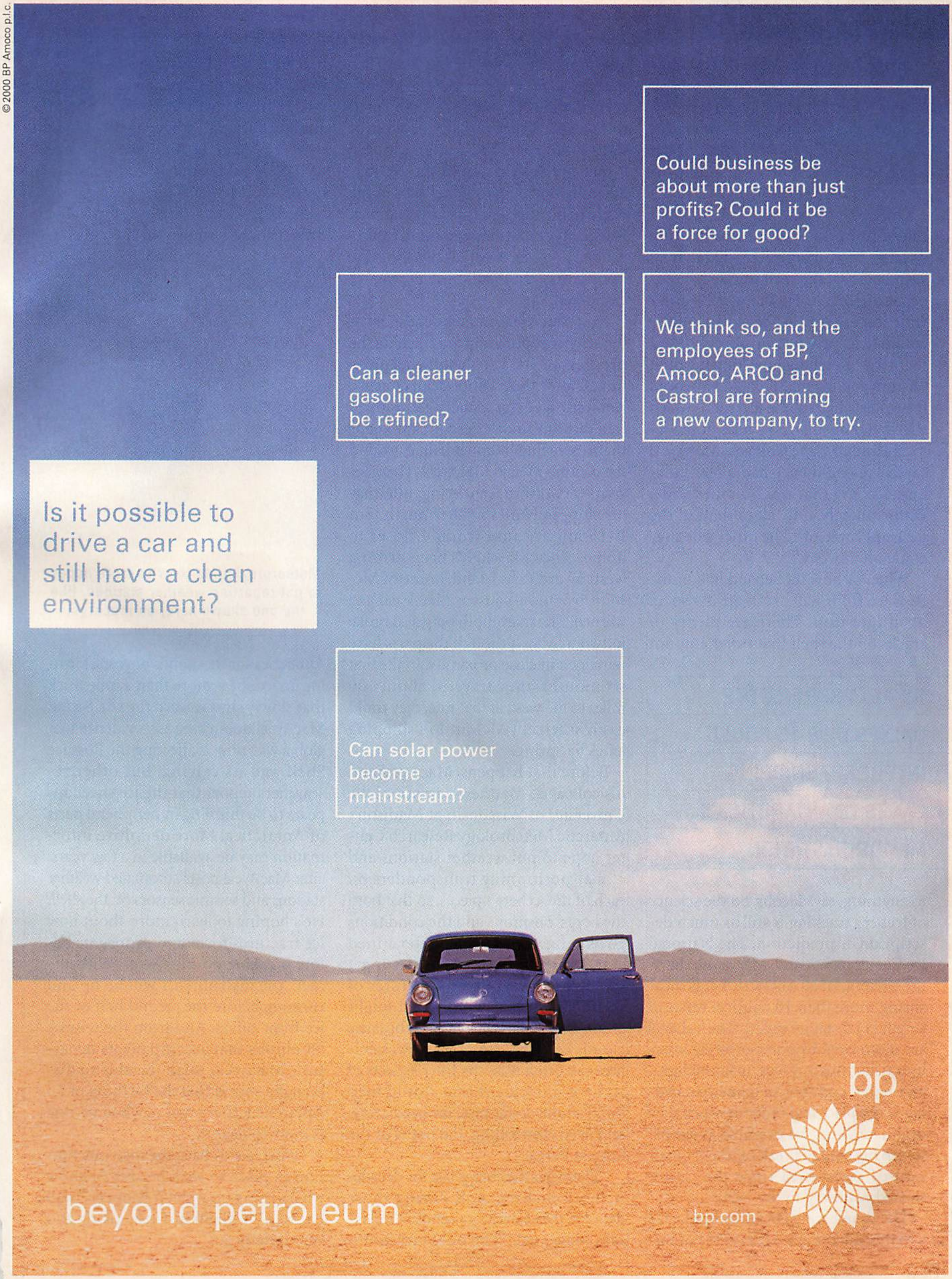

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→ images, MacAyeal could detect cracks in the ice sheet parallel to the front and spaced about 20 miles apart. Icebergs seemed to be breaking off at the cracks, like sections of a chocolate bar, as the ice sheet flowed slowly but surely toward the Ross Sea.

Only one or two major bergs had calved from the Ross ice front during its latest 50-year advance. So MacAyeal suspected that the shelf was due for another big break. He knew a 20-mile-wide iceberg was in the works, but he couldn't say when it would split. And there was no telling how long it would be from end to end. "It could have been the whole length of the ice front," which stretches more than 300 miles from Victoria Land to Cape Colbeck, MacAyeal says. "We could have had a 300-mile-long iceberg that was 20 miles wide. Unfortunately, only about half of the ice front came off. The other side may come off any day."

When or how the second half of the Ross ice front will break off is also an open question. There are plenty of cracks on the shelf that never amount to anything, says Jacobs. So the science of iceberg tracking is still as much description as prediction. The National Ice Center in Suitland, Maryland, charts the position of all Antarctic bergs measuring more than 10 nautical miles in length [11.5 statute miles]. The icebergs are monitored by polar-orbiting satellites using microwaves, infrared light, and radar, and they're named according to the place and order in which they originate. B-15, for example, is the fifteenth big berg to break off the B quadrant of Antarctica since the center started counting in the 1970s.

BY NEXT SPRING, THE HALVES OF B-15 COULD INTERCEPT SHIPPING LANES TO ANTARCTICA'S MCMURDO STATION

The monitoring isn't systematic: It's a by-product of weekly reviews of images from meteorological satellites. Thus the station manager at McMurdo, concerned about his own weather, spied the satellite image of B-15 a couple of days before the ice center did. He e-mailed the snapshot of the 183-by-23-mile-long berg to Julie Palais in the office of polar programs at the National Science Foundation, who in turn forwarded it to MacAyeal. "Is this the same iceberg that you mentioned last week?" wondered Palais.

Now MacAyeal and his colleagues at the science foundation are tracking the progress of B-15 with some trepidation. Unlike their antipodean cousins, Antarctic icebergs usually get trapped in a circumpolar current that keeps them "swirling like a whirligig around the continent," says MacAyeal. That prevents them from wandering into major shipping lanes farther north. But B-15 might cause trouble closer to home. Since March, it's been drifting west toward Ross Island, home of McMurdo Station—just as MacAyeal had warned. The mammoth berg also broke in two in May, although the parts have remained in close proximity. In the first six months, they traveled about 100 miles to the west; at that rate, they could easily intercept McMurdo's shipping lanes by spring.

Before that happens, MacAyeal and his colleague Matthew Lazzara of the University of Wisconsin at Madison's Antarctic Meteorology Research Center hope to put weather stations and global-positioning transponders on each of the iceberg's pieces, so that both the bergs' positions and the conditions governing them can be determined with greater precision. Satellites aren't so good at relaying local features of weather—such as wind—that might affect iceberg navigation. And because clouds can obscure their view, satellites can often miss the finer aspects of iceberg movement that would help build a knowledge base for predicting, and even controlling, the paths of the biggest bergs.

"These giant icebergs last for decades without melting, and during those decades, they travel thousands of miles," says MacAyeal. "The only problem is that their travel is undirected. In the back of my head there's an inkling of a possibility that we might learn enough about icebergs to someday direct one up to Los Angeles. An iceberg the size of B-15 would supply the city's water needs for 500 years."

And the water would be pure as the driven snow—snow that has covered Antarctica for thousands of years, forming an ice sheet more than a mile thick that slowly slips toward the sea. So far, MacAyeal doesn't see any evidence that global warming is affecting the Ross Ice Shelf and its calving, but other researchers report that the ice sheet appears to be thinning in peripheral parts of Antarctica. More definitive information may be available in a few years, after MacAyeal posts automated weather stations and seismic sensors on the shelf. He's hoping to learn more about how ice fractures form and propagate before breaking off into bergs. With any luck, the instruments will be up and running before the second half of the ice front calves. And from the seismic vibrations that accompany its departure, MacAyeal might be able to discern the sound that the birthing of an Antarctic iceberg makes when no one is there to hear it.

Meteorologist Matthew Lazzara hopes to put reporting weather stations, like the one shown here, on icebergs.

"We'd like to have the instrumentation in place so we'll be able to know what's going on when it happens," says Lazzara. "It might just very gently and very quietly go." ☒

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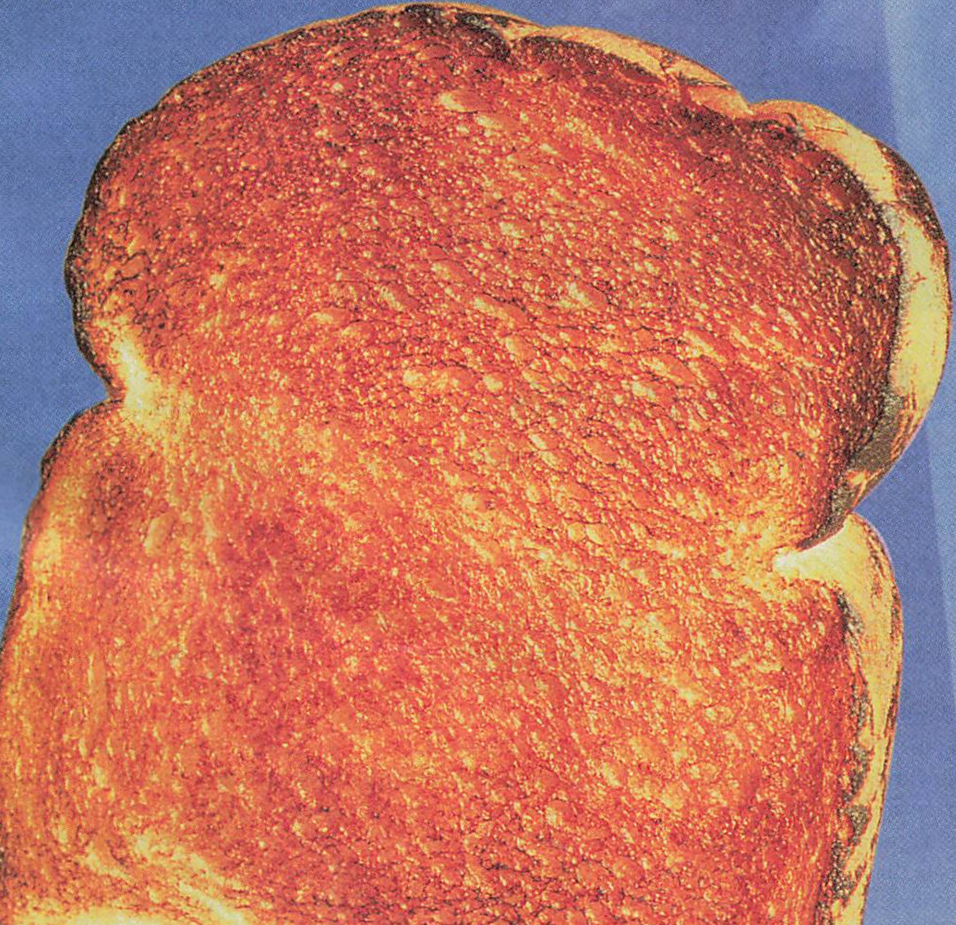

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Risky Business

Calculating the odds of surviving a manned mission to Mars

THIS SUMMER'S RUSSIAN MODULE LAUNCH MARKED A CRITICAL MILESTONE toward a permanent human presence on the International Space Station, but many space buffs would rather see expedited plans for more ambitious and distant missions piloted by people. Recent discoveries indicating subterranean water on Mars and oceans below Europa's ice sheets have renewed calls from the Planetary Society and other advocacy groups to reinstate a goal lost after the last Apollo moon landing in 1972: human exploration beyond Earth orbit.

But NASA seems devoted to robotic probes, which circumvent the difficulties of supporting human life far from terra firma. Space, flight surgeons emphasize, is not exactly a safe place.

Choosing between robots and people is not easy, but with decades of experience behind us, we can at least assemble a list of the hazards humans face off Earth. (Sometimes we can even attach statistics to the dangers. There have been 551 astronaut flights on the shuttle and seven deaths, a one-in-79 chance of not making it.)

Some of this risk assessment comes from learning by doing: We have definitively measured the irreversible bone loss suffered by long-term orbiting astronauts, for example. Other insight comes from reviewing our humbling inability to predict mechanical failures like the abrupt decompression that killed three *Soyuz 11* cosmonauts in 1971.

So far, one fact stands out from the rest—all risks increase as we venture farther from Earth. Just above our atmosphere, at orbiting altitude, separation between atmospheric atoms causes all kinds of havoc. Breathing, of course, becomes impossible, and the thin atmosphere allows high levels of radiation to zing about, not to mention lowering the temperature to 250 degrees below zero.

Farther out, the blast of subatomic particles from the sun would blow through an unprotected astronaut at a million miles per hour. And every 11 years or so, during a cycle of increased solar activity, fierce coronal ejections would hurl lethally dense bursts of atomic debris—at twice their normal speed—toward adventurers.

The moon, the first obvious stop, offers little sanctuary. There, a dozen moon-walking astronauts stood on ground that sizzled at temperatures near the boiling point of water and faced solar radiation more intense than that found in Earth orbit.

Mars isn't much better. The Red Planet's atmosphere offers little oxygen and is so thin at the surface that its pressure is equal to ours at 33,000 feet, the cruising altitude of commercial jets.

Beyond Mars, the news is less gloomy than once believed. Before the Pioneer and Voyager missions, scientists thought that astronauts had less chance of getting through the asteroid belt between Mars and Jupiter than of reaching the tenth stage of Asteroids, the video game. Happily, our robotic probes indicate that the belt's debris is widely spaced.

Once safely through, however, the game gets far tougher. Jupiter's environment becomes lethal long before a spaceship could get close. The gas giant's huge, powerful magnetic field envelops all its moons and sucks loose one ton of material per second from nearby satellite Io alone. The intriguing moon Europa may beckon with possibilities, but as in a Greek myth, it is guarded by fearsome gods. Jupiter's speedy rotation, metallic core, and huge mass create an awesome charged-particle environment that traps and maintains intense radiation.

Beyond Saturn, Uranus and Neptune and Pluto are billions of miles away. The logistics of supporting humans within a rocket for decades on end to travel that far boggle the mind. Indeed, the vulnerability of human life in space may be best measured by the fact that, despite extraordinary precautions, more than a dozen astronauts have died within just a few miles of Earth. ☒

Jupiter's mass is 318 times that of Earth, yet because it rotates more than twice as fast, it creates a magnetic field, called the magnetosphere, that is larger than the sun's. If your eyes could detect it from the surface of Earth, it would appear bigger than the full moon.

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Welcome to the future →

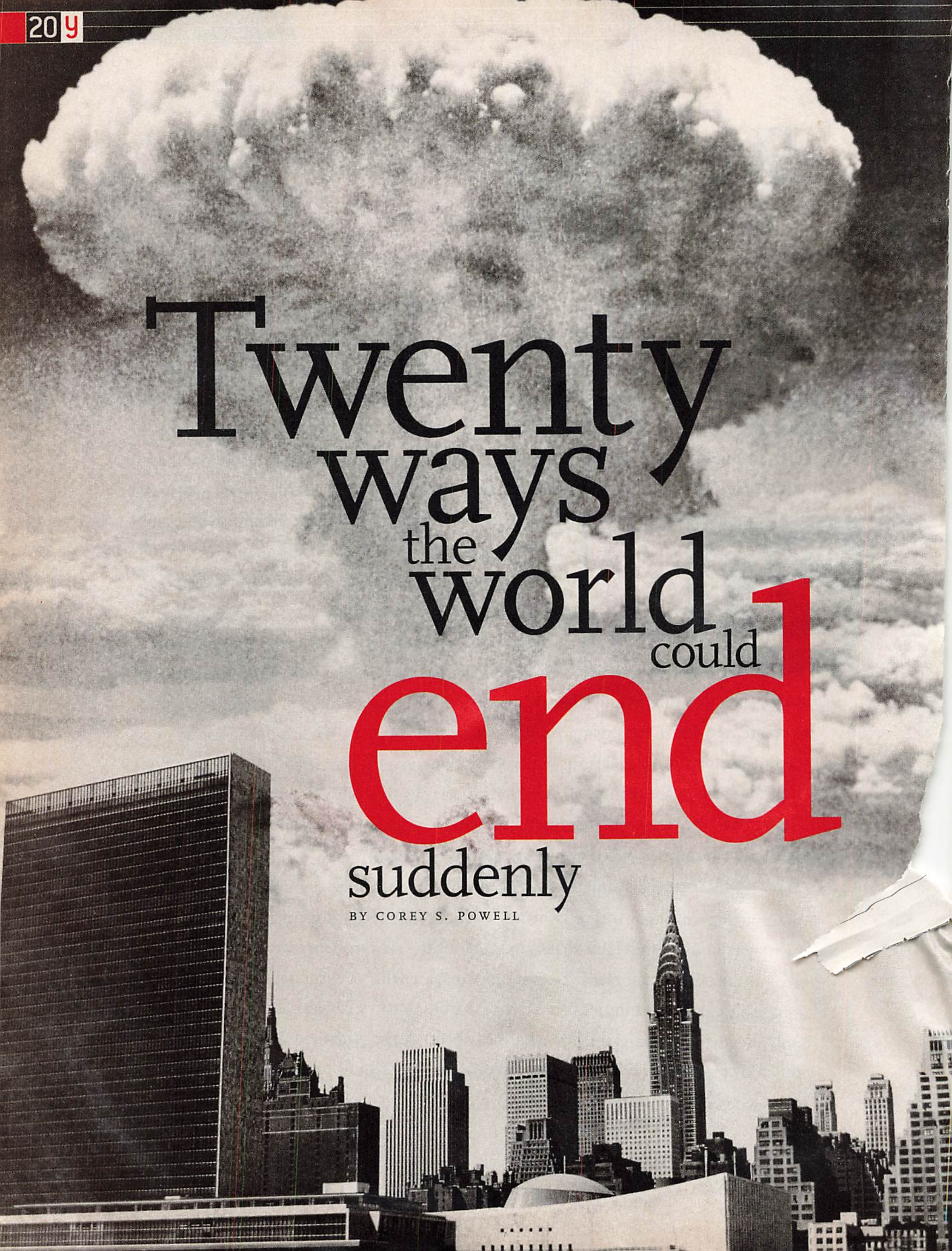
IN THE INAUGURAL ISSUE OF *DISCOVER* 20 YEARS AGO THIS MONTH, Leon Jaroff, the magazine's founding editor, wrote that we had crossed into an era in which "people may still fail to understand science, but they cannot be smug about their deficiency. What science does, and how, flashes persistently across our lives with an immediacy that demands a new kind of comprehension." Two decades later, Jaroff's observation remains true. You hold in your hands the healthy, vibrant proof—a magazine that sells a million copies every month to readers who cherish it because they know how much their lives are affected by science and technology, and they want to comprehend it.

20y

That need to "get it" is greater than ever before because the pace of change driven by science constantly threatens to become overwhelming. You do not want to be behind this curve. Just a few examples: Guided by our mushrooming knowledge of genetics, we are on the verge of figuring out how to create new life-forms using parts of existing life-forms. We are in the midst of a revolution in communications spurred by the convergence of computers, phones, and TVs—all transmitting wirelessly. And, thanks to a NASA probe scheduled for launch next spring, we are within reach of answering many of the greatest cosmological questions ever asked about the nature of the universe.

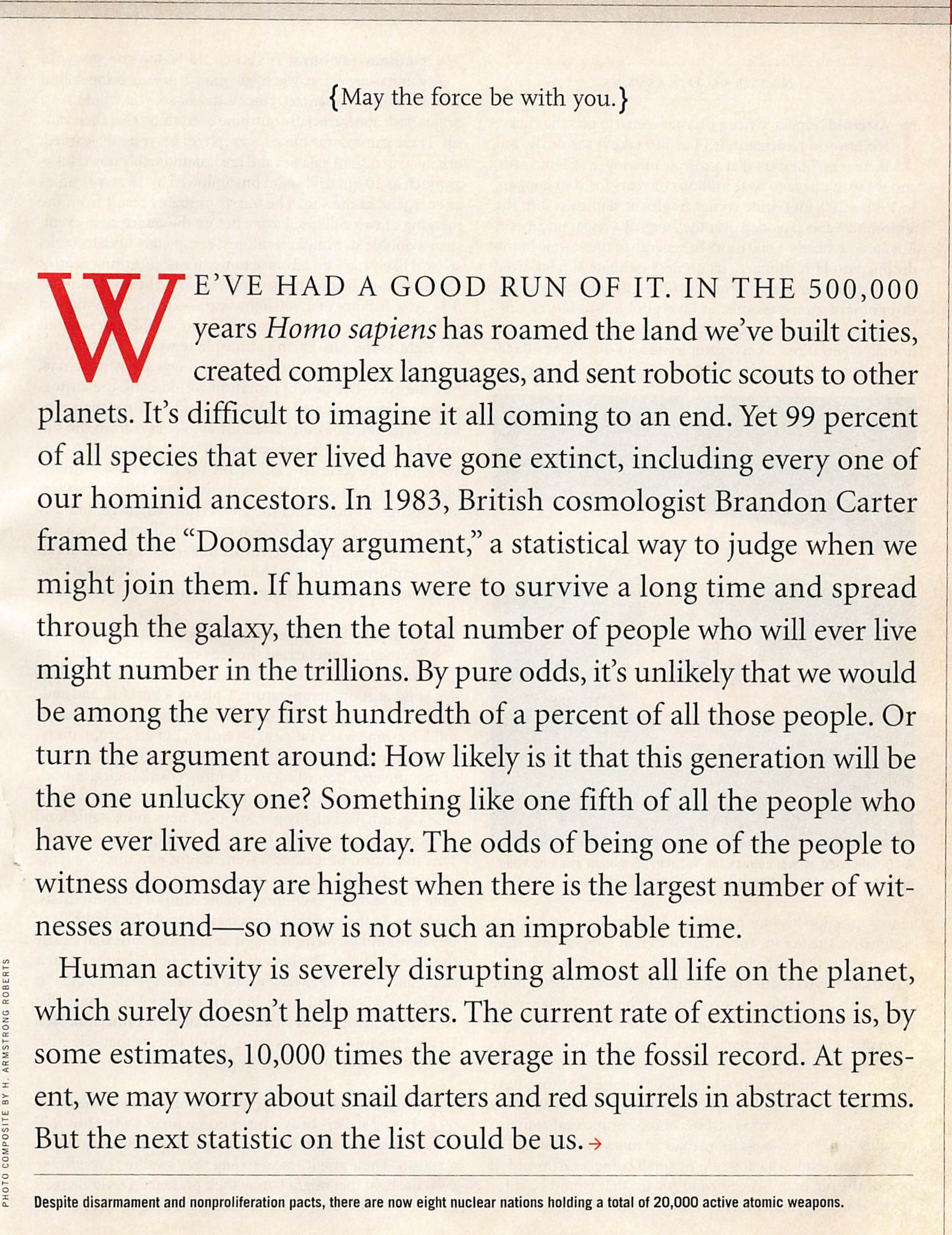
That's why *Discover* is aimed squarely at you, at readers who demand to understand our amazing shifting world of knowledge. That's why the editors of *Discover* think of the magazine as nothing less than a manual for the new millennium. And that's why all of us are excited and pleased—not only to share with you important observations about the significant moments in science during our first 20 years but also to boldly look ahead and prepare you for what lies ahead during the next 20 years. We hope you enjoy this very special issue and that you will be with us each month in the years ahead as we help illuminate the way.

Stephen L. Petranek



Twenty ways the world could end suddenly

BY COREY S. POWELL



{May the force be with you.}

WE'VE HAD A GOOD RUN OF IT. IN THE 500,000 years *Homo sapiens* has roamed the land we've built cities, created complex languages, and sent robotic scouts to other planets. It's difficult to imagine it all coming to an end. Yet 99 percent of all species that ever lived have gone extinct, including every one of our hominid ancestors. In 1983, British cosmologist Brandon Carter framed the "Doomsday argument," a statistical way to judge when we might join them. If humans were to survive a long time and spread through the galaxy, then the total number of people who will ever live might number in the trillions. By pure odds, it's unlikely that we would be among the very first hundredth of a percent of all those people. Or turn the argument around: How likely is it that this generation will be the one unlucky one? Something like one fifth of all the people who have ever lived are alive today. The odds of being one of the people to witness doomsday are highest when there is the largest number of witnesses around—so now is not such an improbable time.

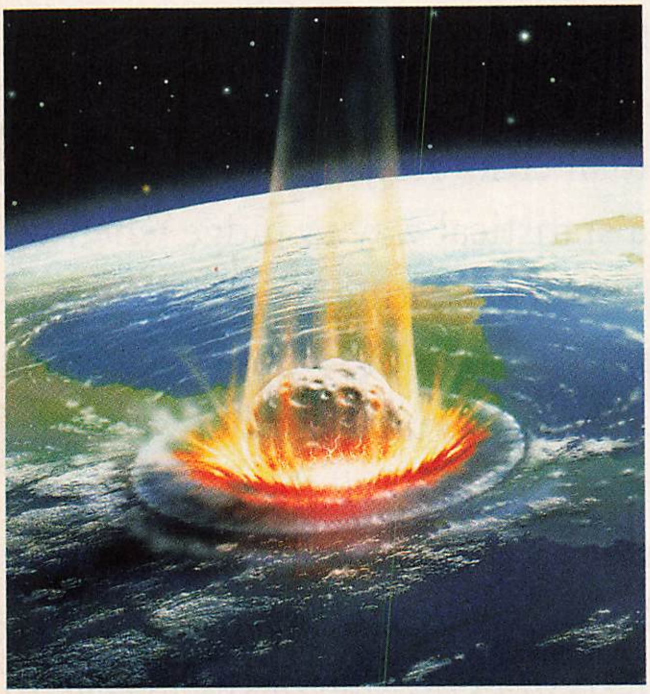
Human activity is severely disrupting almost all life on the planet, which surely doesn't help matters. The current rate of extinctions is, by some estimates, 10,000 times the average in the fossil record. At present, we may worry about snail darters and red squirrels in abstract terms. But the next statistic on the list could be us. →

Despite disarmament and nonproliferation pacts, there are now eight nuclear nations holding a total of 20,000 active atomic weapons.

PHOTO COMPOSITE BY H. ARMSTRONG ROBERTS

NATURAL DISASTERS

1 **Asteroid impact** Once a disaster scenario gets the cheesy Hollywood treatment, it's hard to take it seriously. But there is no question that a cosmic interloper will hit Earth, and we won't have to wait millions of years for it to happen. In 1908 a 200-foot-wide comet fragment slammed into the atmosphere and exploded over the Tunguska region in Siberia, Russia, with nearly 1,000 times the energy of the atomic bomb dropped on Hiroshima. Astronomers estimate similar-sized events occur every one to three centuries. Benny Peiser, an anthropologist-*cum*-pessimist at Liverpool John Moores University in England, claims that impacts have repeatedly disrupted human civilization. As an example, he says one killed 10,000 people in the Chinese city of Chi'ing-yang in 1490. Many scientists question his interpretations: Impacts are most likely to occur over the ocean, and small ones that happen over land are most likely to affect unpopulated areas. But with big asteroids, it doesn't matter much where they land. Objects more than a half-mile wide—which strike Earth every 250,000 years or so—would touch off firestorms followed by global cooling from dust kicked up by the impact. Humans would likely survive, but civilization might not. An asteroid five miles wide would cause major extinctions, like the one that may have marked the end of the age of dinosaurs. For a real chill, look to the Kuiper belt, a zone just beyond Neptune that contains roughly 100,000 ice-balls more than 50 miles in diameter. The Kuiper belt sends a steady rain of small comets earthward. If one of the big ones headed right for us, that would be it for pretty much all higher forms of life, even cockroaches.



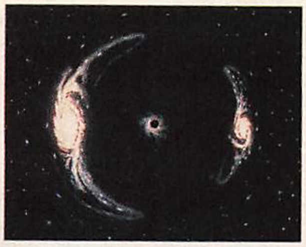
A 10-mile-wide asteroid struck the Yucatán 65 million years ago and probably caused the extinction of the dinosaurs. We could be next.

DAVID A. HARDY/SPL/PHOTO RESEARCHERS

2 **Gamma-ray burst** If you could watch the sky with gamma-ray vision, you might think you were being stalked by cosmic paparazzi. Once a day or so, you would see a bright flash appear, briefly outshine everything else, then vanish. These gamma-ray bursts, astrophysicists recently learned, originate in distant galaxies and are unfathomably powerful—as much as 10 quadrillion (a one followed by 16 zeros) times as energetic as the sun. The bursts probably result from the merging of two collapsed stars. Before the cataclysmal event, such a double star might be almost completely undetectable, so we'd likely have no advance notice if one is lurking nearby. Once the burst begins, however, there would be no missing its fury. At a distance of 1,000 light-years—farther than most of the stars you can see on a clear night—it would appear about as bright as the sun. Earth's atmosphere would initially protect us from most of the burst's deadly X rays and gamma rays, but at a cost. The potent radiation would cook the atmosphere, creating nitrogen oxides that would destroy the ozone layer. Without the ozone layer, ultraviolet rays from the sun would reach the surface at nearly full force, causing skin cancer and, more seriously, killing off the tiny photosynthetic plankton in the ocean that provide oxygen to the atmosphere and bolster the bottom of the food chain. All the gamma-ray bursts observed so far have been extremely distant, which implies the events are rare. Scientists understand so little about these explosions, however, that it's difficult to estimate the likelihood of one detonating in our galactic neighborhood.

3 **Collapse of the vacuum** In the book *Cat's Cradle,* Kurt Vonnegut popularized the idea of "ice-nine," a form of water that is far more stable than the ordinary kind, so it is solid at room temperature. Unleash a bit of it, and suddenly all water on Earth transforms to ice-nine and freezes solid. Ice-nine was a satirical invention, but an abrupt, disastrous phase transition is a possibility. Very early in the history of the universe, according to a leading cosmological model, empty space was full of energy. This state of affairs, called a false vacuum, was highly precarious. A new, more stable kind of vacuum appeared and, like ice-nine, it quickly took over. This transition unleashed a tremendous amount of energy and caused a brief runaway expansion of the cosmos. It is possible that another, even more stable kind of vacuum exists, however. As the universe expands and cools, tiny bubbles of this new kind of vacuum might appear and spread at nearly the speed of light. The laws of physics would change in their wake, and a blast of energy would dash everything to bits. "It makes for a beautiful story, but it's not very likely," says Piet Hut of the Institute for Advanced Studies in Princeton, New Jersey. He says he worries more about threats that scientists are more certain of—such as rogue black holes.

4 **Rogue black holes** Our galaxy is full of black holes, collapsed stellar corpses just a dozen miles wide. How full? Tough question. After all, they're called black holes for a reason. Their gravity is so strong they swallow everything, even the light that might betray their presence. David Bennett of Notre Dame University in Indiana managed to spot two



One way to find a black hole is by watching it bend starlight.

black holes recently by the way they distorted and amplified the light of ordinary, more distant stars. Based on such observations, and even more on theoretical arguments, researchers guesstimate there are about 10 million black holes in the Milky Way.

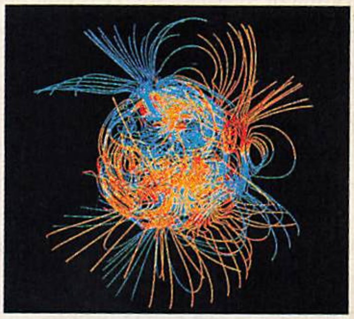
These objects orbit just like other stars, meaning that it is not terribly likely that one is headed our way. But if a normal star were moving toward us, we'd know it. With a black hole there is little warning. A few decades before a close encounter, at most, astronomers would observe a strange perturbation in the orbits of the outer planets. As the effect grew larger, it would be possible to make increasingly precise estimates of the location and mass of the interloper. The black hole wouldn't have to come all that close to Earth to bring ruin; just passing through the solar system would distort all of the planets' orbits. Earth might get drawn into an elliptical path that would cause extreme climate swings, or it might be ejected from the solar system and go hurtling to a frigid fate in deep space.

5 **Giant solar flares** Solar flares—more properly known as coronal mass ejections—are enormous magnetic outbursts on the sun that bombard Earth with a torrent of high-speed subatomic particles. Earth's atmosphere and magnetic field negate the potentially lethal effects of ordinary flares. But while looking through old astronomical records, Bradley Schaefer of Yale University found evidence that some perfectly normal-looking, sunlike stars can brighten briefly by up to a factor of 20. Schaefer believes these stellar flickers are caused by superflares, millions of times more powerful than their common cousins. Within a few hours, a superflare on the sun could fry Earth and begin disintegrating the ozone layer (see #2). Although there is persuasive evidence that our sun doesn't engage in such excess, scientists don't know why superflares happen at all, or whether our sun could exhibit milder but still disruptive behavior. And while too much solar activity could be deadly, too little of it is problematic as well. Sallie Baliunas at the Harvard-Smithsonian Center for Astrophysics says many solar-type stars pass through extended quiescent periods, during which they become nearly 1 percent dimmer. That might not sound like much, but a similar downturn in the sun could send us into another ice age. Baliunas cites evidence that decreased solar activity contributed to 17 of the 19 major cold episodes on Earth in the last 10,000 years.

Solar flares, which peak in frequency every 11 years, interfere with telecommunications and power lines. "Superflares" could be lethal.

BOTTOM: SPACE TELESCOPE SCIENCE INSTITUTE/NASA/S

6 **Reversal of Earth's magnetic field** Every few hundred thousand years Earth's magnetic field dwindles almost to nothing for perhaps a century, then gradually reappears with the north and south poles flipped. The last such reversal was 780,000 years ago, so we may be overdue. Worse, the strength of our magnetic field has decreased about 5 percent in the past century. Why worry in an age when GPS has made compasses obsolete? Well, the magnetic field deflects particle storms and cosmic rays from the sun, as well as even more energetic subatomic particles from deep space. Without magnetic protection, these particles would strike Earth's atmosphere, eroding the already beleaguered ozone layer (see #5). Also, many creatures navigate by magnetic reckoning. A magnetic reversal might cause serious ecological mischief. One big caveat: "There are no identifiable fossil effects from previous flips," says Sten Odenwald of the NASA Goddard Space Flight Center. "This is most curious." Still, a disaster that kills a quarter of the population, like the Black Plague in Europe, would hardly register as a blip in fossil records.

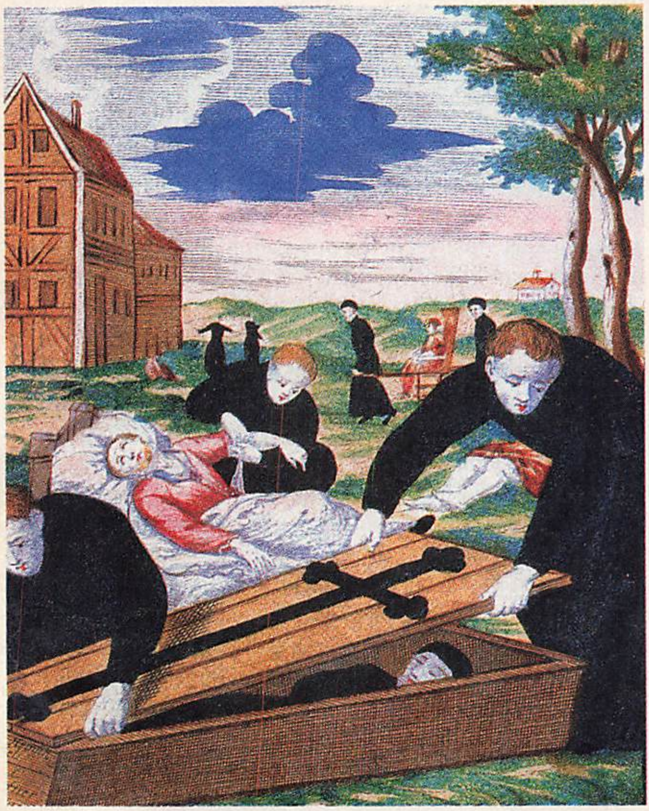


A dynamo in Earth's core makes, and breaks, the protective magnetic field.

7 **Flood-basalt volcanism** In 1783, the Laki volcano in Iceland erupted, spitting out three cubic miles of lava. Floods, ash, and fumes wiped out 9,000 people and 80 percent of the livestock. The ensuing starvation killed a quarter of Iceland's population. Atmospheric dust caused winter temperatures to plunge by 9 degrees in the newly independent United States. And that was just a baby's burp compared with what the Earth can do. Sixty-five million years ago, a plume of hot rock from the mantle burst through the crust in what is now India. Eruptions raged century after century, ultimately unleashing a quarter-million cubic miles of lava—the Laki eruption 100,000 times over. Some scientists still blame the Indian outburst, not an asteroid, for the death of the dinosaurs. An earlier, even larger event in Siberia occurred just about the time of the Permian-Triassic extinction, the most thorough extermination known to paleontology. At that time 95 percent of all species were wiped out.

Sulfurous volcanic gases produce acid rains. Chlorine-bearing compounds present yet another threat to the fragile ozone layer—a noxious brew all around. While they are causing short-term destruction, volcanoes also release carbon dioxide that yields long-term greenhouse-effect warming.The last big pulse of flood-basalt volcanism built the Columbia River plateau about 17 million years ago. We're ripe for another.

8 **Global epidemics** If Earth doesn't do us in, our fellow organisms might be up to the task. Germs and people have always coexisted, but occasionally the balance gets out of whack. The Black Plague killed one European in four during the 14th century; influenza took at least 20 million lives between 1918 and 1919; the AIDS epidemic has produced a similar death toll and is still going strong. From 1980 to 1992, reports the Centers for Disease Control and Prevention, mortality from infectious disease in the United States rose 58 percent. Old diseases such as cholera and measles have developed new resistance to antibiotics. Intensive agriculture and land development is bringing humans closer to animal pathogens. International travel means diseases can spread faster than ever. Michael Osterholm, an infectious disease expert who recently left the Minnesota Department of Health, described the situation as "like trying to swim against the current of a raging river." The grimmest possibility would be the emergence of a strain that spreads so fast we are caught off guard or that resists all chemical means of control, perhaps as a result of our stirring of the ecological pot. About 12,000 years ago, a sudden wave of mammal extinctions swept through the Americas. Ross MacPhee of the American Museum of Natural History argues the culprit was extremely virulent disease, which humans helped transport as they migrated into the New World.



Plague, caused by the bacterium *Yersinia pestis*, killed perhaps 20 million in medieval Europe, transforming the culture and economy.

HUMAN-TRIGGERED DISASTERS

9 **Global warming** The Earth is getting warmer, and scientists mostly agree that humans bear some blame. It's easy to see how global warming could flood cities and ruin harvests. More recently, researchers like Paul Epstein of Harvard Medical School have raised the alarm that a balmier planet could also assist the spread of infectious disease by providing a more suitable climate for parasites and spreading the range of tropical pathogens (see #8). That could include crop diseases which, combined with substantial climate shifts, might cause famine. Effects could be even more dramatic. At present, atmospheric gases trap enough heat close to the surface to keep things comfortable. Increase the global temperature a bit, however, and there could be a bad feedback effect, with water evaporating faster, freeing water vapor (a potent greenhouse gas), which traps more heat, which drives carbon dioxide from the rocks, which drives temperatures still higher. Earth could end up much like Venus, where the high on a typical day is 900 degrees Fahrenheit. It would probably take a lot of warming to initiate such a runaway greenhouse effect, but scientists have no clue where exactly the tipping point lies.

A warmer climate might mean more flooding, crop loss, and disease.

10 **Ecosystem collapse** Images of slaughtered elephants and burning rain forests capture people's attention, but the big problem—the overall loss of biodiversity—is a lot less visible and a lot more serious. Billions of years of evolution have produced a world in which every organism's welfare is intertwined with that of countless other species. A recent study of Isle Royale National Park in Lake Superior offers an example. Snowy winters encourage wolves to hunt in larger packs, so they kill more moose. The decline in moose population allows more balsam fir saplings to live. The fir trees pull carbon dioxide out of the atmosphere, which in turn influences the climate. It's all connected. To meet the demands of the growing population, we are clearing land for housing and agriculture, replacing diverse wild plants with just a few varieties of crops, transporting plants and animals, and introducing new chemicals into the environment. At least 30,000 species vanish every year from human activity, which means we are living in the midst of one of the greatest mass extinctions in Earth's history. Stephen Kellert, a social ecologist at

LEFT: JEAN-LOUP CHARMET/SPL/PHOTO RESEARCHERS; P ARMSTRONG ROBERTS

Yale University, sees a number of ways people might upset the delicate checks and balances in the global ecology. New patterns of disease might emerge (see #8), he says, or pollinating insects might become extinct, leading to widespread crop failure. Or as with the wolves of Isle Royale, the consequences might be something we'd never think of, until it's too late.

11 **Biotech disaster** While we are extinguishing natural species, we're also creating new ones through genetic engineering. Genetically modified crops can be hardier, tastier, and more nutritious. Engineered microbes might ease our health problems. And gene therapy offers an elusive promise of fixing fundamental defects in our DNA. Then there are the possible downsides. Although there is no evidence indicating genetically modified foods are unsafe, there are signs that the genes from modified plants can leak out and find their way into other species. Engineered crops might also foster insecticide resistance. Longtime skeptics like Jeremy Rifkin worry that the resulting superweeds and superpests could further destabilize the stressed global ecosystem (see #9). Altered microbes might prove to be unexpectedly difficult to control. Scariest of all is the possibility of the deliberate misuse of biotechnology. A terrorist group or rogue nation might decide that anthrax isn't nasty enough and then try to put together, say, an airborne version of the Ebola virus. Now there's a showstopper.

***Homo erectus* persisted 1.5 million years, *Homo habilis* less than a million. When will scattered skulls be all that's left of *Homo sapiens*?**

12 **Particle accelerator mishap** Theodore Kaczynski, better known as the Unabomber, raved that a particle accelerator experiment could set off a chain reaction that would destroy the world. Surprisingly, many sober-minded physicists have had the same thought. Normally their anxieties come up during private meetings, amidst much scribbling on the backs of used envelopes. Recently the question went public when London's *Sunday Times* reported that the Relativistic Heavy Ion Collider (RHIC) on Long Island, New York, might create a subatomic black hole that would slowly nibble away our planet. Alternately, it might create exotic bits of altered matter, called strangelets, that would obliterate whatever ordinary matter they met. To assuage RHIC's jittery neighbors, the lab's director convened a panel that rejected both scenarios as pretty much impossible. Just for good measure, the panel also dismissed the possibility that RHIC would trigger a phase transition in the cosmic vacuum energy (see #3). These kinds of reassurances follow the tradition of the 1942 "LA-602" report, a once-classified document that explained why the detonation of the first atomic bomb almost surely would not set the atmosphere on fire. The RHIC physicists did not, however, reject the fundamental possibility of the disasters. They argued that their machine isn't nearly powerful enough to make a black hole or destabilize the vacuum. Oh, well. We can always build a bigger accelerator.

New particle accelerators will soon match the destructive energy of cosmic rays.

13 **Nanotechnology disaster** Before you've even gotten the keyboard dirty, your home computer is obsolete, largely because of incredibly rapid progress in miniaturizing circuits on silicon chips. Engineers are using the same technology to build crude, atomic-scale machines, inventing a new field as they go called nanotechnology. Within a few decades, maybe sooner, it should be possible to build microscopic robots that can assemble and replicate themselves. They might perform surgery from inside a patient, build any desired product from simple raw materials, or explore other worlds. All well and good if the technology works as intended. Then again, consider what K. Eric Drexler of the Foresight Institute calls the "grey goo problem" in his book *Engines of Creation,* a cult favorite among the nanotech set. After an industrial accident, he writes, bacteria-sized machines, "could spread like blowing pollen, replicate swiftly, and reduce the biosphere to dust in a matter of days." And Drexler is actually a strong proponent of the technology. More pessimistic souls, such as Bill Joy, a cofounder of Sun Microsystems, envision nano-machines as the perfect precision military or terrorist tools.

14 **Environmental toxins** From Donora, Pennsylvania, to Bhopal, India, modern history abounds with frightening examples of the dangers of industrial pollutants. But the poisoning continues. In major cities around the world, the air is thick with diesel particulates, which the National Institutes of Health now considers a carcinogen. Heavy metals from industrial smokestacks circle the globe, even settling in the pristine snows of Antarctica. Intensive use of pesticides in farming guarantees runoff into rivers and lakes. In

LEFT: CAMERIQUE/H. ARMSTRONG ROBERTS; RIGHT: DAVID PARKER/SPL/PHOTO RESEARCHERS

high doses, dioxins can disrupt fetal development and impair reproductive function—and dioxins are everywhere. Your house may contain polyvinyl chloride pipes, wallpaper, and siding, which belch dioxins if they catch fire or are incinerated. There are also the unknown risks to think about. Every year NIH adds to its list of cancer-causing substances—the number is up to 218. Theo Colburn of the World Wildlife Fund argues that dioxins and other, similar chlorine-bearing compounds mimic the effects of human hormones well enough that they could seriously reduce fertility. Many other scientists dispute her evidence, but if she's right, our chemical garbage could ultimately threaten our survival.

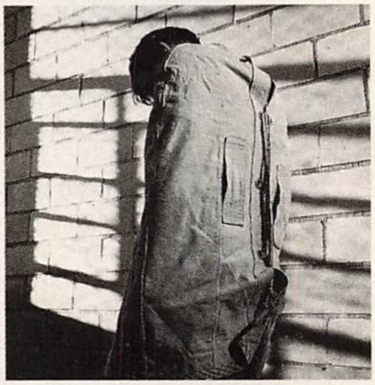
Full-body suits protected soldiers against chemical weapons during the Gulf War. Civilians get no such help for environmental toxins.

WILLFUL SELF-DESTRUCTION

15 **Global war** Together, the United States and Russia still have almost 19,000 active nuclear warheads. Nuclear war seems unlikely today, but a dozen years ago the demise of the Soviet Union also seemed rather unlikely. Political situations evolve; the bombs remain deadly. There is also the possibility of an accidental nuclear exchange. And a ballistic missile defense system, given current technology, will catch only a handful of stray missiles—assuming it works at all. Other types of weaponry could have global effects as well. Japan began experimenting with biological weapons after World War I, and both the United States and the Soviet Union experimented with killer germs during the cold war. Compared with atomic bombs, bioweapons are cheap, simple to produce, and easy to conceal. They are also hard to control, although that unpredictability could appeal to a terrorist organization. John Leslie, a philosopher at the University of Guelph in Ontario, points out that genetic engineering might permit the creation of "ethnic" biological weapons that are tailored to attack primarily one ethnic group (see #11).

16 **Robots take over** People create smart robots, which turn against us and take over the world. Yawn. We've seen this in movies, TV, and comic books for decades. After all these years, look around and still—no smart robots. Yet Hans Moravec, one of the founders of the robotics department of Carnegie Mellon University, remains a believer. By 2040, he predicts, machines will match human intelligence, and perhaps human consciousness. Then they'll get even better. He envisions an eventual symbiotic relationship between human and machine, with the two merging into "postbiologicals" capable of vastly expanding their intellectual power. Marvin Minsky, an artificial-intelligence expert at MIT, foresees a similar future: People will download their brains into computer-enhanced mechanical surrogates and log into nearly boundless files of information and experience. Whether this counts as the end of humanity or the next stage in evolution depends on your point of view. Minsky's vision might sound vaguely familiar. After the first virtual-reality machines hit the marketplace around 1989, feverish journalists hailed them as electronic LSD, trippy illusion machines that might entice the user in and then never let him out. Sociologists fretted that our culture, maybe even our species, would whither away. When the actual experience of virtual reality turned out to be more like trying to play Pac-Man with a bowling ball taped to your head, the talk died down. To his credit, Minsky recognizes that the merger of human and machine lies quite a few years away.

17 **Mass insanity** While physical health has improved in most parts of the world over the past century, mental health is getting worse. The World Health Organization estimates that 500 million people around the world suffer from a psychological disorder. By 2020, depression will likely be the second leading cause of death and lost productivity, right behind cardiovascular disease. Increasing human life spans may actually intensify the problem, because people have more years to experience the



Mental problems are exacerbated by war and poverty around the world.

LEFT: DENNIS BRACK/BLACK STAR; RIGHT: JERRY COOKE/PHOTO RESEARCHERS loneliness and infirmity of old age. Americans over 65 already are disproportionately likely to commit suicide.

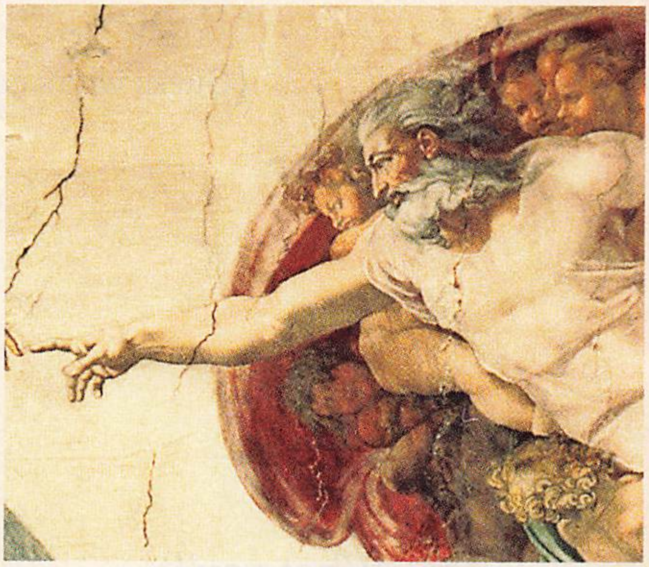
Gregory Stock, a biophysicist at the University of California at Los Angeles, believes medical science will soon allow people to live to be 200 or older. If such an extended life span becomes common, it will pose unfathomable social and psychological challenges. Perhaps 200 years of accumulated sensations will overload the human brain, leading to a new kind of insanity or fostering the spread of doomsday cults, determined to reclaim life's endpoint. Perhaps the current trends of depression and suicide among the elderly will continue. One possible solution—promoting a certain kind of mental well-being with psychoactive drugs such as Prozac—heads into uncharted waters. Researchers have no good data on the long-term effects of taking these medicines.

A Greater Force Is Directed Against Us

18 **Alien invasion** At the SETI Institute in Mountain View, California, a cadre of dedicated scientists sifts through radio static in search of a telltale signal from an alien civilization. So far, nothing. Now suppose the long-sought message arrives. Not only do the aliens exist, they are about to stop by for a visit. And then... any science-fiction devotee can tell you what could go wrong. But the history of human exploration and exploitation suggests the most likely danger is not direct conflict. Aliens might want resources from our solar system (Earth's oceans, perhaps, full of hydrogen for refilling a fusion-powered spacecraft) and swat us aside if we get in the way, as we might dismiss mosquitoes or beetles stirred up by the logging of a rain forest. Aliens might unwittingly import pests with a taste for human flesh, much as Dutch colonists reaching Mauritius brought cats, rats, and pigs that quickly did away with the dodo. Or aliens might accidentally upset our planet or solar system while carrying out some grandiose interstellar construction project. The late physicist Gerard O'Neill speculated that contact with extraterrestrial visitors could also be socially disastrous. "Advanced western civilization has had a destructive effect on all primitive civilizations it has come in contact with, even in those cases where every attempt was made to protect and guard the primitive civilization," he said in a 1979 interview. "I don't see any reason why the same thing would not happen to us."

Never mind abductions—worry about pests they may leave behind.

19 **Divine intervention** Judaism has the Book of Daniel; Christianity has the Book of Revelation; Islam has the coming of the Mahdi; Zoroastrianism has the countdown to the arrival of the third son of Zoroaster. The stories and their interpretations vary widely, but the underlying concept is similar: God intervenes in the world, bringing history to an end and ushering in a new moral order. Apocalyptic thinking runs at least back to Egyptian mythology and right up to Heaven's Gate and Y2K mania. More worrisome, to the nonbelievers at least, are the doomsday cults that prefer to take holy retribution into their own hands. In 1995, members of the Aum Shinri Kyo sect unleashed sarin nerve gas in a Tokyo subway station, killing 12 people and injuring more than 5,000. Had things gone as intended, the death toll would have been hundreds of times greater. A more determined group armed with a more lethal weapon—nuclear, biological, nanotechnological even—could have done far more damage.



Will God bring the world to an end? Or will some group presuming to act on God's behalf bring about an all-too-human apocalypse?

20 **Someone wakes up and realizes it was all a dream** Are we living a shadow existence that only fools us into thinking it is real? This age-old philosophical question still reverberates through cultural thought, from the writings of William S. Burrows to the cinematic mind games of *The Matrix.* Hut of the Institute of Advanced Studies sees an analogy to the danger of the collapse of the vacuum. Just as our empty space might not be the true, most stable form of the vacuum, what we call reality might not be the true, most stable form of existence. In the fourth century B.C., Taoist philosopher Chuang Tzu framed the question in more poetic terms. He described a vivid dream. In it, he was a butterfly who had no awareness of his existence as a person. When he awoke, he asked: "Was I before Chuang Tzu who dreamt about being a butterfly, or am I now a butterfly who dreams about being Chuang Tzu?" ☒

—with additional research by Diane Martindale

Oh Auntie Em, how do I know I'm not still in Oz, dreaming of Kansas?

TOR HABBICK VISIONS/SPL/PHOTO RESEARCHERS; TOP AND BOTTOM RIGHT: FPG INTERNATIONAL

{Guess who's coming to dinner?}

1 What you'll need to know in twenty years that you don't know now

BY JOSEPH D'AGNESE
ILLUSTRATIONS BY ROSS MACDONALD

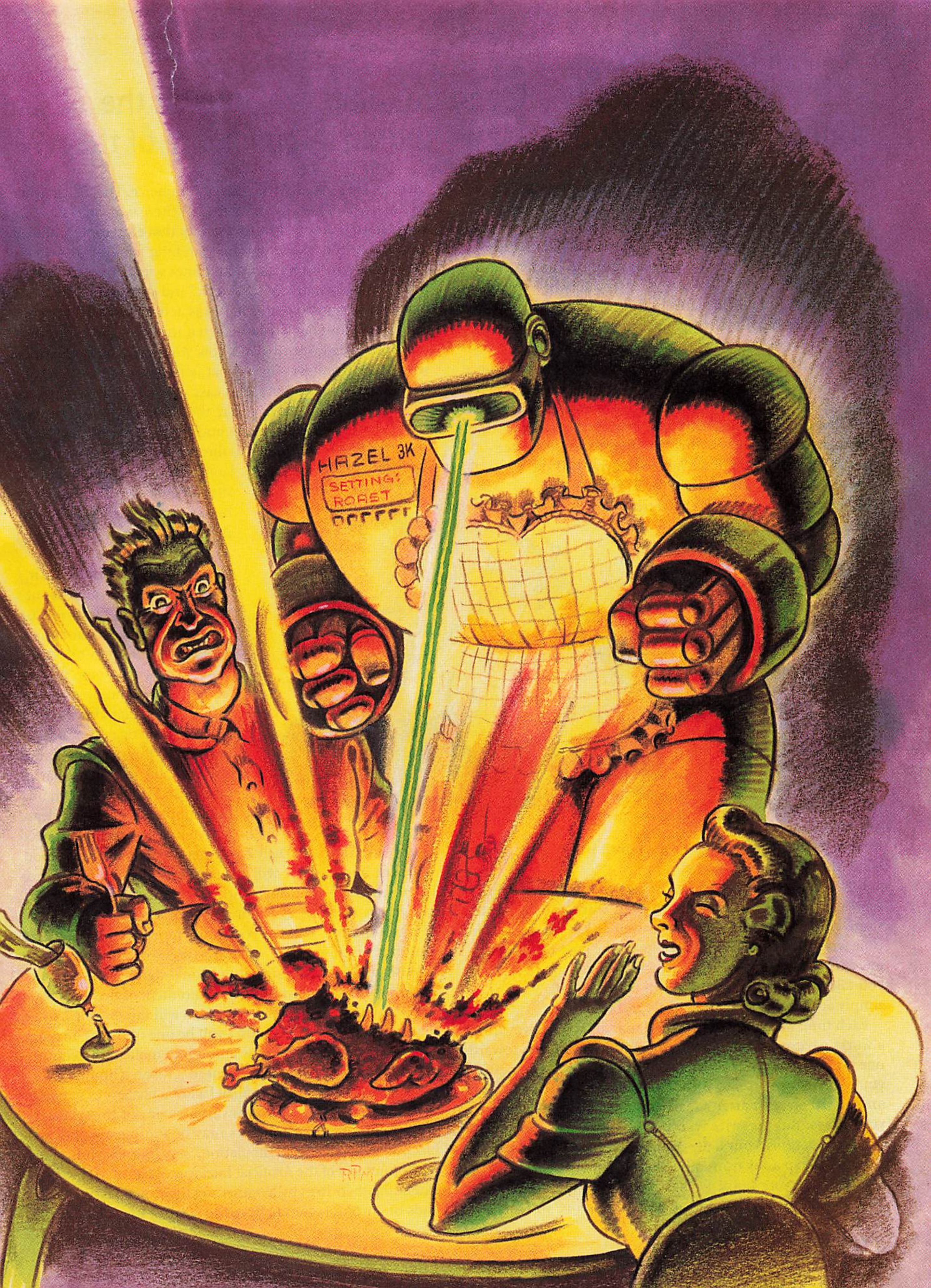
YOU KNOW THINGS, YOU CHILD OF THE 21ST century. You may not stop to think about it, but you know stuff to get along in the year 2000 that your hallowed progenitors could never have dreamed of. You know how to delete. You can pull down a menu. You know how to change the channel on your TV without getting out of your overstuffed chair, a luxury your grandparents did not enjoy. You know—or should know—how to keep your kid from downloading porn on the Internet. You even know the word download. You know other words too. Scary words. Ebola, mad cow, West Nile virus. At the very mention of these words, your mind knows to give you the creeps.

As always, knowledge is power. What you know gets you through your day. Protects your family. Keeps them safe.

And what you need to know has changed—a lot. Twenty years ago, you took notes with a pen, not a pointer pushed across the face of a personal digital assistant. Twenty years ago you still thought a mouse was just a rodent. Had some prescient soul sidled up to you on the street in 1980 and said, "Listen, buddy, soon you're going to need to know how to operate a big glowing box on your desk by sliding a plastic thing around," you would have seen him as a madman, not a prophet.

By the year 2020, **you will need to know stuff you can hardly guess today.** You've heard all this before. You're hip to this technology thing. You know the drill: Gadgets change; you adapt to the gadgets. You learn new buzzwords, talk the talk, and keep on going as humans have for millennia. But in doing so, you reduce technology to a heap of glorified hand tools, the equivalent of sticks chimps use to extract ants from a hole.

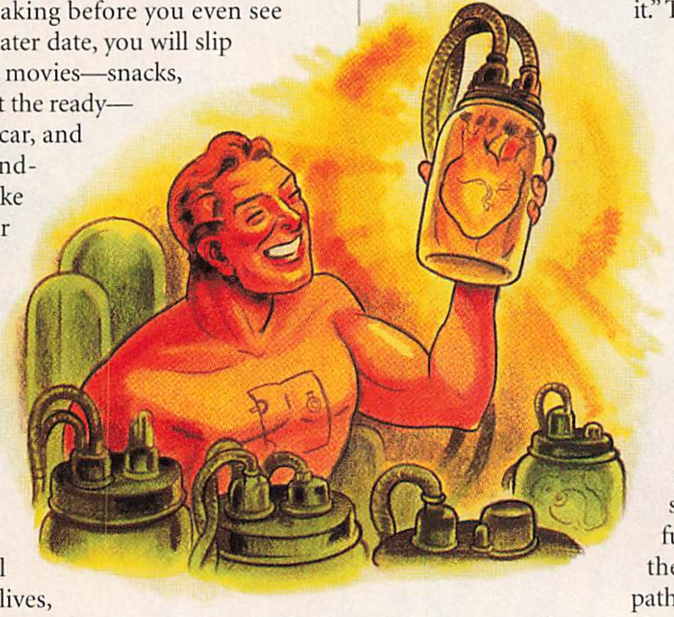
In 20 years it should be painfully clear that technology never just hands us tools; it grants us a passport to a world where choices multiply, desires are ignited, and new moral decisions confront us. Like an odyssey-starved traveler, you'll wander through a kind of exotic street fair, senses assaulted by too much information. You'll find yourself frazzled just trying to draw a bead on all the options, while a numbing calliope tune insists it's all great fun. A lot of what you'll encounter will just be cool, requiring nothing more than nimble minds and fingers. By the year 2020, for example, **you will need to know how to talk to your house.** Today your home contains dozens


HAZEL 3K
SETTING: ROAST
RPM

More than 200,000 centenarians will inhabit the United States in 2020—why shouldn't you be one of them?

of appliances, each working independently. But someday you'll cross the threshold and everything will know you're home. The lights will flicker on, the air conditioner will have kicked in, the refrigerator will clamor to enumerate all the meals you can assemble with the groceries cached inside. In exchange for this convenience, you'll share your abode with a horde of circuit-heavy infants that constantly burble to each other and cry out for your care. If you're the one with mechanical flair at your house, when you come through the door at night, your spouse will be pulling you aside to whisper, "Honey, I need you to talk to the robot."

By the year 2020, **you will have to learn to drive a more automated car.** You'll get behind the wheel of a smart car that avoids fender benders by braking before you even see danger looming. At a much later date, you will slip into a bucket seat as if at the movies—snacks, reading material, and sodas at the ready—sit back, relax, program the car, and over the freeways to grandmother's house you'll go. Like the toaster and coffeemaker back home, the car's sensors will monitor the activity and destinations of other cars on the road. "Going my way?" your vehicle will bleep in autospeak. "Indeed," responds the living room on wheels in the left lane. And the two will hitch up and rocket toward their common goal together. This technology will conserve fuel and may save lives, but the pleasure of driving as you know it will be gone. That's something you should know.



But perhaps by now you've realized that for every convenience technology bestows upon us, it chips away at something else. All of us, great souls as well as lost ones, must in time wrestle with this notion. If you are the poet Blake, in metered rhyme you decry the Satanic mills; if you are Kaczynski, you take to the hills and spit death by snail mail. Most of us simply acknowledge the trade-offs and move on.

Each time we do this, though, we march farther away from a world we can touch and comprehend in our bones toward one that we pray will work better. Consider: In the year 2020, **you'll identify yourself, gain access to homes and businesses, and board aircraft after a laser has measured the shape of your irises.** But the price will be loss of privacy. A record of your transactions, your daily comings and goings, will be just a keyboard tap away from others.

Booting up your home PC has already become a public act. Meander the Web today, and almost every move you make is cataloged in service to the gods of commerce. They know what you're buying. What you listen to. Where you chat. By 2020 **you'll need to know how to clean up that electronic trail day in and day out.** "Say you were searching for information on hats," theorizes Jaron Lanier, computer scientist, musical composer, and virtual reality pioneer, "and you saw a link about hats, but when you got to it, it was actually a weird pornography site about hat fetishes. Then it turns out there's a record that you visited this site, and now you're getting bombarded with offers from people with hat fetishes. Furthermore, your friends are being contacted in case they have hat fetishes. All of a sudden you're the hat fetish person in your social circle, and you have to go in and undo it." To throw the hounds off your scent, Lanier says, you could spend the afternoon downloading the Great Books or posing as a do-gooder in search of charities deserving of your drachmas.

In time, you'll be wielding electronica for the same reasons medieval crusaders took up sword and lance: to ward off intruders. Rooting out destructive viruses and spam in your equipment will become old hat, as will the regular checks you'll be performing on your groceries and yourself. Tomorrow's Kaczynskis will be able to concoct harmful viruses and insinuate them into the food supply, or perhaps release pathogens in public places. You'll need to be ready for them. Daily computer checkups of your blood, saliva, or bodily waste will be effortless, the medical equivalent of checking your stock portfolio. "Real-time monitoring," says James Weiland, assistant professor of ophthalmology at Johns Hopkins, "will tell you in the morning what vitamin your body is low on and what to have for breakfast."

With all this new information, you'll stand a better chance of living well beyond your biblical allotment of threescore and ten. More than 200,000 centenarians will inhabit the United States in 2020—why shouldn't you be one of them? To reach that age **you'll need to know enough to make more complicated medical choices:** Do I want to jettison a limb and wait five years to regrow another? Shall I allow a phalanx of nanobots to scrape the plaque out of my arteries or opt to replace the vessels altogether? "Amateurs may be fooling around with black-market genetic manipulation," says Marvin Minsky, one of the founders of the Artificial Intelligence Lab at MIT, "maybe extending their lives by lengthening their own telomeres, the ends of chromosomes believed to control life span. Or they

Why not design your kid, toes up, out of whole cloth: the blue-eye gene, the blond-hair gene, the excel-at-lacrosse gene?

might, in fact, be growing new features in their brain."

By the year 2020, science will understand the Creator's software well enough to tell you a great deal about the genetic hand dealt you and those you love. Science may even help you decide if you should quit loving them. These days it's not unheard of for one partner to investigate the other's background or assets before marrying. In the future **you'll need to access your betrothed's genetic map,** see what diseases he or she is likely to contract, assess the appearance and health of your children, and perhaps even size up your love's mental health. Of course, this swings both ways. In this world, you will be forced to ask: Do I want to know if I'm earmarked for heart disease or breast cancer? Do I want my potential spouse to know? If I know this, and my doctor knows, does it mean that my insurance carrier must know? If this last one scares you, it should. It could mean the end of health care as you know it.

This is just the beginning. Once we know the future, we're going to be tempted to rewrite the software. Clearly, it would be an act of kindness to reach into that fragile, permeable, four- or eight-cell being and rid it of the disease that cut short the life of its great-grandfather. But why wait for conception? Why not design your kid, toes up, out of whole cloth: the blue-eye gene, the blond-hair gene, the excel-at-lacrosse gene. Ban such tinkering, and citizens will merely scurry underground in order to conceive the perfect child.

If we can tear ourselves away from such selfish goals long enough to look around, **we will have to face the fact that technology favors some and eclipses others.** Bill Robinson, who spent 30 years as an electrical engineer with Canada's Nortel Networks, has been thinking about this issue recently. "We spend our time and effort creating exciting new communications technologies," he writes, "yet half the world does not have access to a telephone. We use the Internet to order the latest novel, yet many people in the world don't have access to books. We are now discussing embedded processors to connect our refrigerators to bathroom scales and the grocery store, yet many children in the world go to bed hungry at night."

This grisly reality will be harder to hide from when our planet swells to 8 billion people in 2020. For Lanier, the most heartbreaking scenario is festering in the third world, where, he believes, the current generation of children—lacking food, lacking skills, lacking aid, lacking education—will be lost in the next techno-revolution. "What is going to happen to all these people as they start to age, say, 20 years from now?" he wonders. **"You're going to have to somehow live while you watch a billion people starve,** which is going to be a new human experience. How will we do that?"

Good question. And just one of many difficult questions waiting. How can I choose between two genetic scripts for a child I have yet to know? How much of myself should I reveal on the Web? How will I cope with all these machines when they break down, including the self-replicating nanopests that may be residing in my flesh? In our zeal to be happy little technologists, we'll turn, much as we do today, to the Web for answers. And we'll perfect the art of being disappointed.

If any medium ever resembled the human unconscious, the Web is it: a place of hidden wonders, stray inane thoughts, peaks of brilliance, valleys of perversity. And no apparent governor. Type your query, hit return, and voilà!—10,000 hits. Good luck shaking them down. Even in 2020 **you will always need to know if the facts you've dredged up are accurate and truthful.** With so many sources doling out information, you will need to know: What is he selling, and why is he selling it? Most unsettling is the fact that these precious touchstones are not permanent. They never will find their way to the library stacks. Instead we are moving closer to Orwell's nightmare: the truth ceaselessly modified, altered, edited, or altogether obliterated. Here today, gone tomorrow, with nothing but a bewildering ERROR 404 FILE NOT FOUND left in its place.

By then, you will no longer be a child of the 21st century. If anything, you'll be an elder, your mind and body augmented, your chromosomes refreshed, flexible computers woven into the four corners of your garments. On the one hand, your workload will multiply as you bat away each glitch resulting from the increased number of gadgets in your life. On the other, **you will be forced to take on moral questions no human has ever faced.** When will you find time to do that? How will you contemplate when everything is speeding up and time for reflection is practically nonexistent?

That's you in 20 years. Like the machine that inspired your age, you will be constantly scanning, processing, sifting, searching for a code to guide you through. And yet the key, the compass, the answer, was once offered in a temple at Delphi. What will you need to know in 2020? Yourself. ⊠

—reported by Glenn Garelik

{And then there were none.}

Twenty species we may lose in the next twenty years

BY JACK McCLINTOCK

We may be losing 30,000 species a year. Some scenarios predict 50 percent of living species could be lost in 50 years

THE MOUNTAIN GORILLA OF CENTRAL AFRICA, largest and rarest of the apes and one of our closest relatives, is down to several hundred individuals. If it ever goes extinct—and it easily could in the next 20 years—there will be headlines around the world and cries of anguish about what could have been done. We're good at noting the disappearance of distinctive creatures, if we know about it, because we've had to do that so many times before. They become what Harvard biologist E. O. Wilson calls animal celebrities.

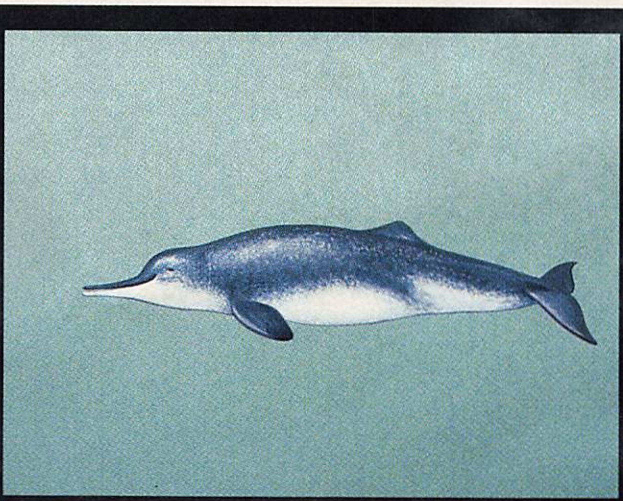
Because handsome animals like the mountain gorilla (see photograph, previous page) attract attention and protection, they stand a better chance of surviving than their more obscure, and much more numerous, brethren. But fame didn't save the dusky seaside sparrow—one of the most recent well-documented extinctions of a vertebrate in the United States—and it may not save the giant panda, the Sumatran rhinoceros, the Chinese river dolphin, or the leatherback turtle.

In the past 20 years, thanks to the twin revolutions in computing and genetics, we know more than ever before about the marvelous genetic diversity and surprising kinship of species on Earth. But just as biologists are beginning to reckon the importance of biodiversity to the planet's history and health, the species themselves are vanishing. In the United States alone, we've recently documented the loss of the Santa Barbara song sparrow, the blue pike of the Great Lakes, and Sampson's pearly mussel, a freshwater bivalve mollusk native to the Wabash River in Illinois and Indiana. Other plants and animals have probably slipped away, unnoticed.

Elsewhere, the tally mounts too. We've lost the strange gastric brooding frog of Australia, which incubated its young in

The species pictured on these pages face what biologist Peter Jackson calls "a massive extinction not seen since the dinosaurs died."

Iberian lynx



Chinese river dolphin

Sumatran rhinoceros

Aye-aye

PREVIOUS PAGE: MICHAEL NICHOLS/MAGNUM PHOTOS; THIS PAGE (LEFT TO RIGHT): O. ALAMANY AND E. VICENS/CORBIS; RICHARD ELLIS/PHOTO RESEARCHERS; TOM BRAKEFIELD/DRK PHOTO; DENNIS/GALLO IMAGES/CORBIS

its stomach and gave birth through its mouth. During the brooding period, the mother's stomach stopped producing acids. If scientists had learned how that acid production was shut off, it might have helped them develop a new ulcer treatment for humans. We've also probably lost the brilliant golden toad, with its great dark liquid eyes, once a tourist attraction in the forests of Costa Rica. The list of extinctions is frighteningly varied: more than a dozen species of the colorful Oahu tree snail; long-legged bush wrens of New Zealand; about 180 different species of the once numerous cichlids of Lake Victoria, Africa; the flowering *Hibiscus liliflorus* of Rodrigues Island in the Indian Ocean. All have died off in the past two decades. Thousands more species are just hanging on.

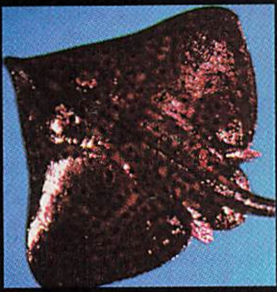
"We're on the verge of the seventh great extinction," says Wilson. While cosmic accident or climate change used to be the cause of such biological cataclysms, humans alone are responsible for nearly every loss of species in the past few thousand years. Since the advent of *Homo sapiens,* Wilson says, extinctions have occurred 100 to 100,000 times faster than before, principally because we have degraded and destroyed forests, spread agriculture, introduced animals into new environments, and polluted the air, water, and soil. There are at least 10 million species on Earth, and experts estimate we're killing 30,000 of them each year, a pace that appears to be increasing. Some scenarios predict that nearly 50 percent of all living species could be lost in the next 50 years. Think of an Earth without elephants, orangutans, giant pandas, rhinoceroses, dolphins, macaws, frogs, frankincense. That's the kind of world we may be entering, an everlasting bear market in species—a period Wilson dubs the Age of Loneliness.

Habitat loss is the single biggest problem. In Hawaii, two thirds of the original forest cover has been destroyed, half of the islands' 140 native bird species are extinct, and 30 more are endangered. Birds of wider range are dying too. The Spix's

Saola

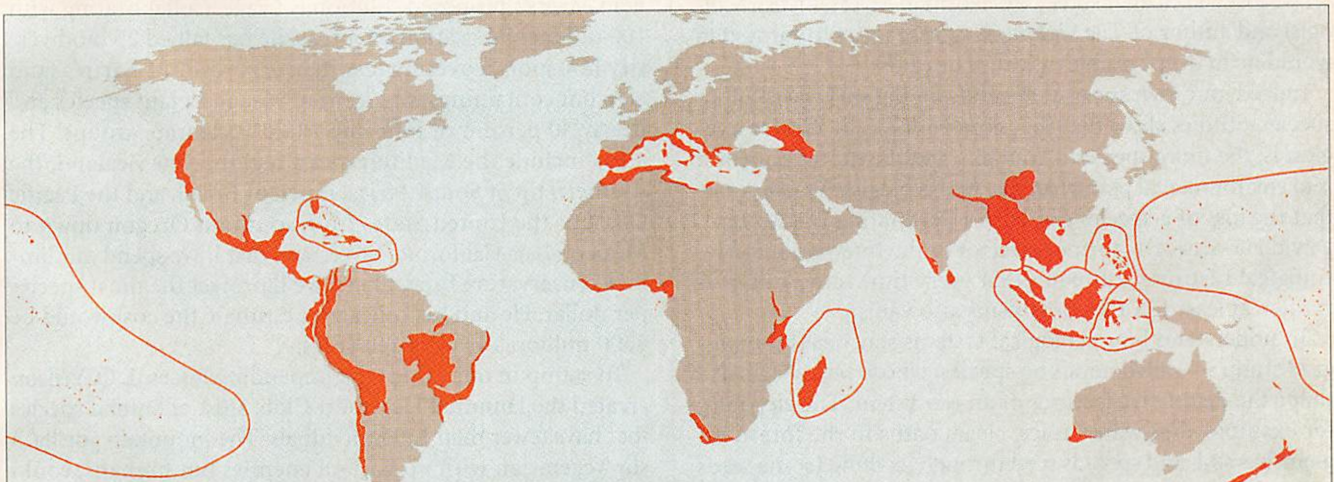
White abalone

Bachman's warbler


Barn-door skate

Javan gibbon

Oahu tree snail



SAVING BIODIVERSITY HOT SPOTS: The areas shown in orange represent 25 exceptionally species-rich regions that are undergoing extensive environmental damage. Protecting these areas from further degradation, some ecologists argue, is the most cost-effective strategy for saving the greatest number of species and staving off impending mass extinctions. The 25 zones make up just 1.4 percent of the land surface on Earth.

FROM TOP, LEFT TO RIGHT: ALAN RABINOWITZ; CALIFORNIA DEPT. OF FISH AND GAME; J.H. DICK/VIREO; DON FLESCHER/NATIONAL MARINE FISHERIES SERVICE, WOODS HOLE; RUSSELL A. MITTERMEIER; UNIVERSITY OF HAWAII, HONOLULU; BOTTOM: MAP BY STEVEN STANKIEWICZ/ADAPTED AND REPRINTED WITH PERMISSION FROM *NATURE*, VOL. 403, P. 853

Keeping a species in a zoo doesn't mean we can keep it alive. You need hundreds of animals for a healthy gene pool

macaw, native to Brazil, is down to a single individual in the wild, and the ivory-billed woodpecker, which once ranged over the southeastern United States, is probably gone altogether. Twelve percent of all surviving bird species worldwide are endangered, reports a BirdLife International study. Roughly a quarter of the world's plant species will be threatened over the next few decades, says Peter Wyse Jackson, of Botanic Gardens Conservation International.

Our primate cousins are particularly vulnerable because they depend on shrinking tropical forests and endangered ecosystems for foraging. Although most have made it through the last 100 years, an estimated 20 percent—some 120 types of prosimians, monkeys, and apes—will be at severe risk of extinction within the next two decades. Among them are some whose faces are as appealing as their names, including the Tonkin snub-nosed monkey, the golden lion tamarin, and Miss Waldron's red colobus monkey.

Extinction is not always a remote event. The African violet continues to thrive in parlors around the world, yet it has all but vanished from its native Kenya and Tanzania. Urban expansion recently wiped out a wetland fern that lived just outside Cape Town, South Africa. "Extinctions are occurring right under our noses," says David Given, chairman of the World Conservation Union's Plant Conservation Committee.

Exactly what we're losing isn't known, because about 90 percent of the disappeared are unnamed, unknown invertebrates—mostly insects—that thrive in tropical rain forests. And insects make the world as we know it work. They play a crucial role in pollination, they devour detritus, and they contain pests. "If we lost half of all insects," says Norman Myers, British ecologist and author of *The Sinking Ark*, "our agricultural system would be in deep trouble in just one year."

Indeed, our own survival depends on the survival of other species. Studies show that the more biologically diverse a region is, the more species it contains and the more resilient it is to environmental perturbations. And ecologists already know that the loss of a species can have a devastating ripple effect. David Hawksworth, former director of the International Mycological Institute, estimates that every time one plant goes extinct, at least 15 other organisms also vanish.

To understand how ecological systems stay healthy, biologists study so-called keystone species, whose behavior helps shape the distinctive features of an ecosystem. The elephant, for example, digs water holes, clears paths in the forest, replenishes soil, and spreads seed through its dung (some seeds will not germinate unless they have passed through an elephant's digestive system). Sea otters control the population of sea urchins that feed on kelp, thus protecting kelp forests, which in turn shelter a variety of marine life and protect coastlines from wave erosion. Unfortunately, we may not learn that a species is a keystone until it's gone and takes others with it.

In many cases, endangered creatures hang on at low numbers until a small event, like an untimely drought, tips the balance toward death. But strong efforts, such as the campaign to protect the American alligator, save endangered species too, depending on the species. The alligator breeds early and often and produces dozens of eggs, so when hunting was banned, the gator rebounded. The Florida panther and the West Indian manatee share some of the alligator's habitat, but they need much more territory and breed far more slowly. Both species could disappear well before 2020.

Some organisms are beyond saving because they can no longer reproduce in the wild. The café marron, native to Rodrigues, a tiny island off Mauritius, is a wild relative of the coffee plant that might contribute genes that would allow coffee-growing in a wider range of soils and elevations, except there's only one plant left. A cutting flown to the Royal Botanic Gardens at Kew in London lived, but it can't set seed because of a faulty stigma. Eventually, it will die off.

"If someone burned down the Louvre, you can be sure people would be outraged," says Russell Mittermeier, president of Conservation International. "We're burning down nature's Louvre, and no one pays attention. Even if we keep a species alive in the zoo, it doesn't mean we can keep the thing alive. You need several hundred animals to keep a healthy gene pool."

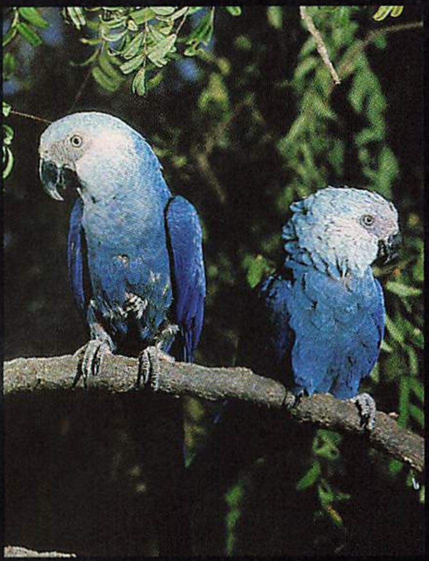
And you need natural habitat. Even the most thoughtful and well-funded zoo programs handle only about 2,000 of the 24,000 species of mammals, birds, reptiles, and amphibians known to exist, Wilson says. So for an endangered species the zoo may be more of a hospice than a rehabilitation center.

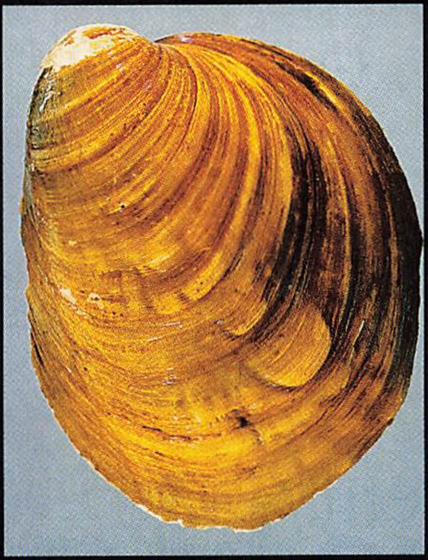
Because rescuing all threatened species is impossible, Norman Myers's proposed solution is triage. Collaborating with 100 other conservation scientists, he has tallied 25 biodiversity hot spots, covering less than 2 percent of Earth's land area but containing 44 percent of vascular plant species and nearly 40 percent of four important vertebrate groups. The areas include the Mediterranean region, New Zealand, the southern tip of South Africa, much of Brazil, and the Pacific Coast of the United States from southern Oregon down to Mexico's Baja California. Myers says that if we spend our limited conservation funds there, we'll protect the most species per dollar. He and his colleagues estimate the cost would be $500 million a year for ten years.

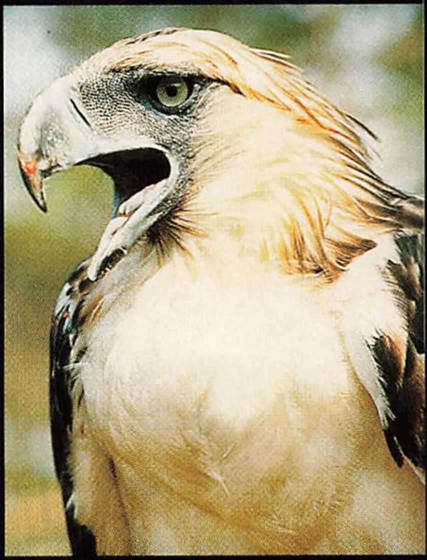
To stamp in our minds the impending losses, E.O. Wilson created the Hundred Heartbeat Club, a list of animal species that have fewer than 100 individuals. The mountain gorilla, a shy vegetarian with no natural enemies but humans, could soon be added to the roster. Its best chance of survival is as a tourist attraction. Other members of the club include Spix's macaw, the Hawaiian crow, the Chinese river dolphin, and the Philippine eagle. But even species with several hundred members face an uncertain future. Members of some highly vulnerable groups appear on the following pages. ☒

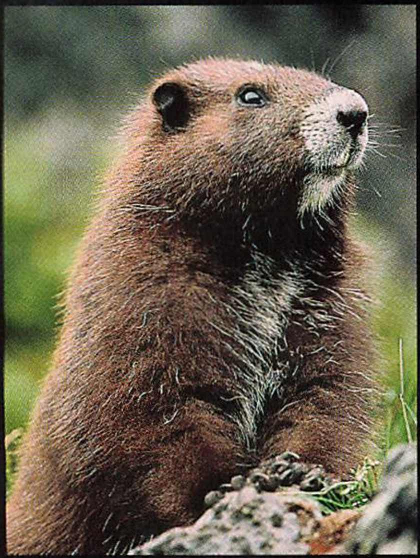
—reporting by Melissa Mertl

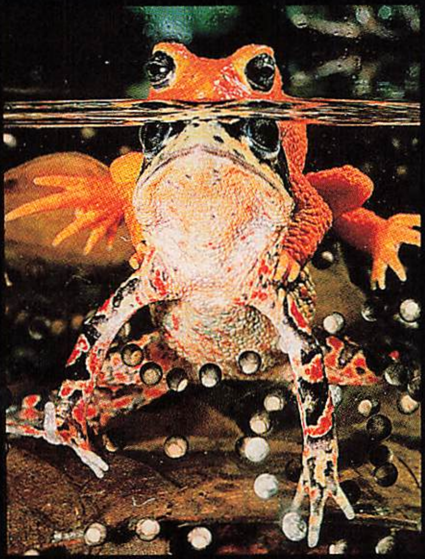
OPPOSITE, LEFT TO RIGHT: CLAUS MEYER/MINDEN PICTURES; K.S. CUMMINGS/INHS; C.B. FRITH/BRUCE COLEMAN INC.; TIM FITZHARRIS/MINDEN PICTURES; MICHAEL FOGDEN/DRK PHOTO; TROTIGNON/JACANA/PHOTO RESEARCHERS; TILO NADLER; DOUG PERRINE/INNERSPACE VISIONS; RON AUSTING/PHOTO RESEARCHERS

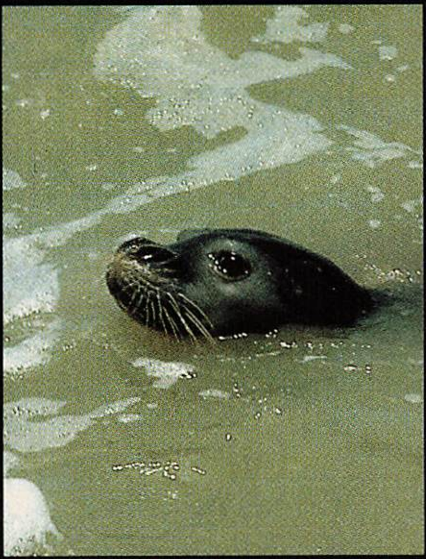

Spix's macaw

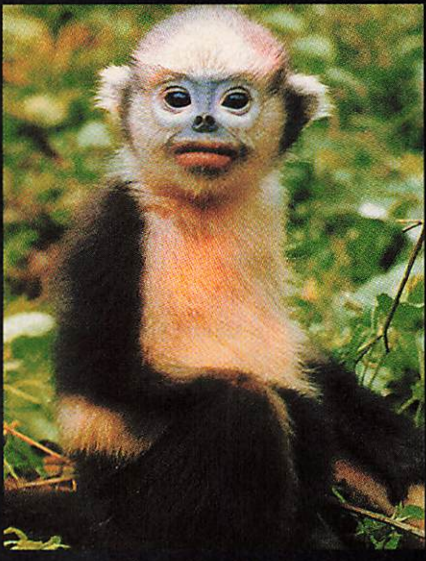

White wartyback mussel

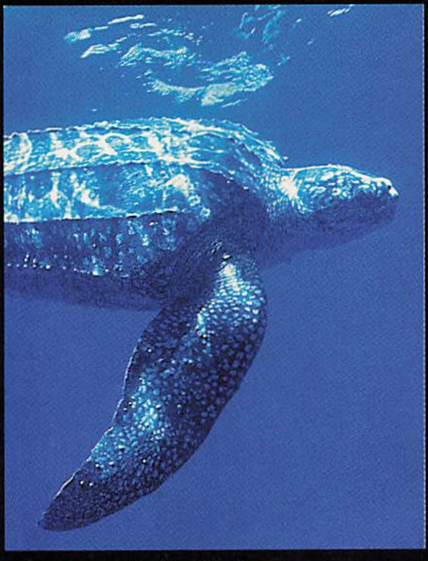

Philippine eagle

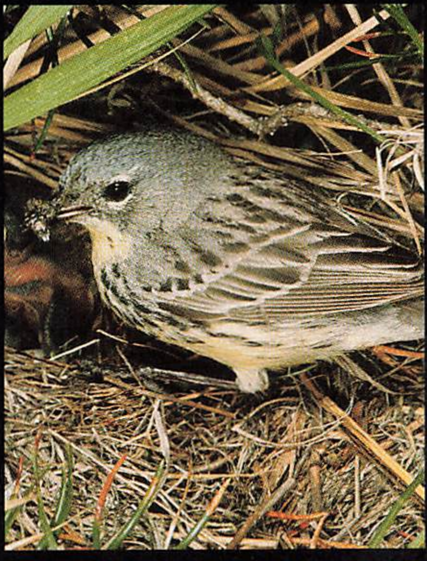

Vancouver Island marmot


Golden toad of Costa Rica


Mediterranean monk seal


Tonkin snub-nosed monkey


Leatherback turtle

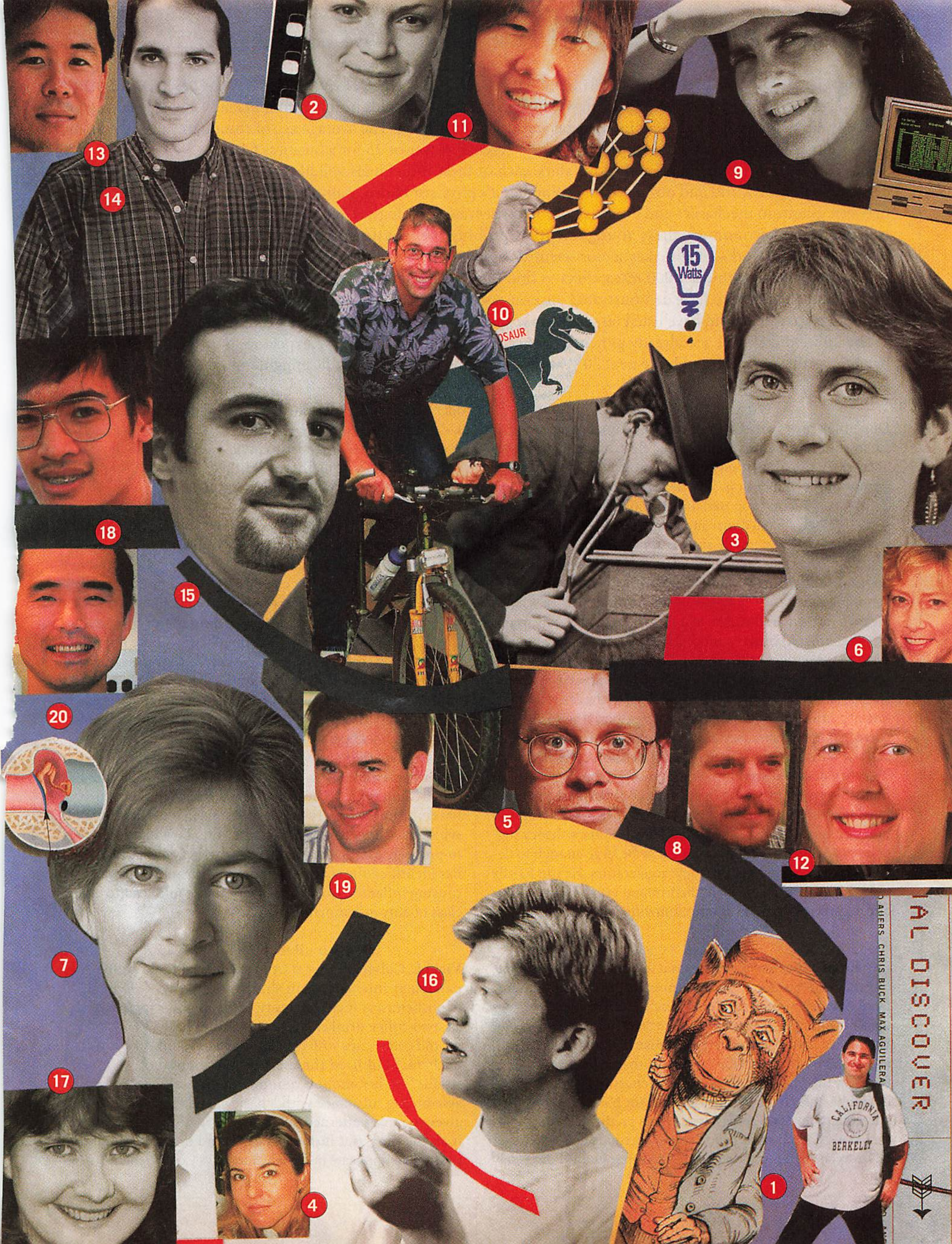

Kirtland's warbler

{The Discover 20.}

• Twenty • scientists to watch in the next twenty years

BY WILLIAM SPEED WEED

1 Nima Arkani-Hamed
2 Annelise E. Barron
3 Carolyn Bertozzi
4 Vicki L. Colvin
5 Christopher C. “Kit” Cummins
6 Gretchen Daily
7 Jennifer A. Doudna
8 B. Scott Gaudi
9 Andrea Ghez
10 David G. Grier
11 Young-Kee Kim
12 Diane Linda Linne
13 Hideo Mabuchi
14 Juan Maldacena
15 Nikola P. Pavletich
16 Daniel Povinelli
17 Daphne Preuss
18 Terry Tao
19 Jereon Tromp
20 Teruhiko Wakayama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AL DISCOVER

SOME OF THEM DISASSEMBLED CARS AND TELEVISIONS WHEN THEY WERE CHILDREN. Others chased grasshoppers or grew orchids. One studied molds from her mom's leftover coffee. Each grew up to be recognized as an intellectual wunderkind early on. The average age of these accomplished scientists is only 33, which is more like 18 for a baseball player or 25 for a business CEO.

Far more than CEOs and sports stars, each of these individuals will likely change our fundamental understanding of the world and our place in it. Whether it's physicist Hideo Mabuchi's discoveries about the interface between quantum mechanics and everyday life or conservation biologist Gretchen Daily's rigorous assessments of ecosystems and economics, these young scientists probing the frontiers of knowledge have already shown the promise—or the work—that makes senior scientists applaud in awe.

Discover surveyed almost 1,000 researchers to find these scientists, asking for nominations of persons under 40 in the United States who have demonstrated once-in-a-generation insight. The response left us optimistic. The talent pool is vast. We could have listed 60 scientists without compromising the quality of the group.

The 20 we did choose are already glowing stars in their respective fields. We expect each of them to shine only brighter as they move through the next 20 years and light the paths to scientific enlightenment.

GRAVITY CHASER

Don't look now (you'd see nothing anyway), but every particle in your body, every quark, every electron, may have a secret gravitational relationship with molecules from another dimension. Several years ago, theoretical physicists proposed that the universe has many more spatial dimensions than the three we know and love: north-south, east-west, up-down—the *x*-, *y*-, and *z*-axes on a three-dimensional graph. **Nima Arkani-Hamed,** 28, an assistant professor of physics at the University of California at Berkeley, is going even further: He theorizes that these other spatial dimensions (seven at present) could be much larger than previously thought. We don't experience these other dimensions because all matter and the three dominant forces of the universe—strong, weak, and electromagnetic—are confined to the obvious three. Gravity, however, is another force altogether. If physicists are correct, it appears weaker than the three dominant forces because it is dispersed through other dimensions. Furthermore, if gravity does transcend other dimensions, then perhaps it is interacting with matter in them. That could explain the missing dark matter of the universe: We can't see it because it's in other dimensions. Arkani-Hamed's revolutionary theory suggests that some of the dimensions may be large enough to detect when we build larger particle accelerators. He can hardly wait: "You can be an excellent theorist and yet go through your entire career without ever once knowing you're right."

CHIP RACER

Scientists may be close to printing out the entire human genome, but they will be able to fully harness the power of that template only when they can "read" each individual's specific DNA sequences. Northwestern University chemical engineer **Annelise E. Barron,** 32, is building devices to do just that. Ultimately, this "lab on a chip," as researchers call it, will be able to tell doctors if a patient has a strep infection, high cholesterol, even a predisposition to cancer. As a step in creating such chips, Barron is working to get DNA from patient blood samples to separate into discretely identifiable bits. So far she has succeeded in creating a workable technology for the laboratory. Now she's looking for speed—real-time, bedside separation of DNA. "When we had the Model T, we could have said, 'Let's stick with that,' " she says. "But it's great to have a Maserati!"

CARBO-LOADER

Scientists run in **Carolyn Bertozzi**'s family, but unlike her father and older sister, who became physicists, she found her calling as a chemist. The 34-year-old associate professor at the University of California at Berkeley is making major inroads in our understanding of carbohydrates. These complex, multiunit sugars or polysaccharides appear to mediate communication between cells, a process vital to immune response and the spread of cancer. Researchers have been stymied trying to figure out exactly how carbohydrate molecules operate because their large, complicated structures make them unwieldy to study. As a result, most biochemistry and drug-discovery work over the decades has centered on proteins because they're much simpler. Bertozzi has come up with a new, small molecule that turns on and off synthesis of a specific carbohydrate, thus allowing researchers to precisely assess its influence on various cells. Already she has identified the central role another carbohydrate plays in causing inflammation, a discovery that could lead to a new class of anti-inflammatory drugs.

NANO-BRICK-BUILDER

Vicki L. Colvin got her start in science with old coffee. "My particular interest was in slime molds," says Colvin, 35, a nanochemist at Rice University. "My mom was an avid coffee drinker, and I was always finding old coffee cups with brilliantly colored stuff in them. I cultured the most highly colored strains." To her, mold is quintessential: a self-assembling substance with a basic shape that gives rise to a patterned, large-scale structure. Nature makes it all the time, but humans have found the task all but impossible to duplicate in the lab. Sure, says Colvin, chemists can

PREVIOUS PAGE: PHOTOMONTAGE BY J.-C. SUARÈS; 14. KRIS SNIBBE; 15. AMOJ CHOW; 10. PAUL RIZZO; 9. SETH JOEL; 13. ROBERT J. PAZ

“I get chills up and down my spine when I think about the possibility of getting insights into the origin of life”

make wonderful molecules, “like Saran Wrap and Viagra. But so far we haven’t been able to be true architects because our molecules are only the bricks, and we have few ways of laying them together to form walls, much less buildings.” If she can learn to mimic self-assembling chemistry, the payoff could be remarkable: Using artificial proteins as tiny building blocks, she might be able to construct new types of lenses and lasers.

CHEMICAL CARPENTER

As a teenager, **Christopher C. “Kit” Cummins** loved to work with the tools readily available at his grandfather’s farm in Wisconsin. He used them to keep the old tractor running and to make furniture. When he graduated from high school he was torn between traveling to Sweden to learn cabinetmaking or going to college. He chose higher learning, but he found a way to keep on tinkering with tools. Now they’re just microscopic. Stephen Lippard, who chairs Cummins’s department at the Massachusetts Institute of Technology, says the 34-year-old chemistry professor is gifted with an ability to find tools that make “unusual—impossible!—chemical transformations.” One example of the power of such transformations was the development of a new process for splitting the nitrogen molecule that makes up about 80 percent of our atmosphere. Scientists had figured out a way of doing so early in the 20th century, and won Nobel prizes for it; the method allowed the synthesis of ammonia, which can be made into artificial fertilizer as well as cleaning solutions. But their process is only possible under extreme pressure conditions. Cummins simplified that by using a tool nature never thought of—a specially shaped “saw” of molybdenum, which neatly cuts the nitrogen molecule into two.

VALUE TRACKER

Critics charge that all **Gretchen Daily** does is traipse through nature and paste a price tag on everything. Ecologists, however, applaud the Stanford University conservation biologist’s work. It’s her job to understand the ecology of an area well enough to predict the economic consequences of land-use decisions. Daily offers a simple example of what can happen without her kind of analysis: In one region of Australia, farmers cleared thousands of acres of trees, arguing the crops they could grow on the land would more than make up for the environmental damage. But afterward, the water table rose. It turned out to be salty and ruined all the croplands. “The fact is we’re devastating life on the planet,” says Daily, 35. “It’s far too late to save everything. We can either continue what we’re doing, blindly, and at a great cost to both the environment and society, or we can start figuring out how we depend on particular ecosystems” and plan our use of them accordingly.

RNA CODE-BREAKER

There are times during long days at her lab at Yale University that **Jennifer A. Doudna** “fantasizes about running off to Hawaii to be a papaya farmer.” No doubt the island-state native would grow great papayas, but the ribonucleic acid (RNA) she cultivates in New Haven may turn out to be much more useful to all of us than a few more acres of fruit. Doudna, a professor of molecular biophysics and biochemistry, is trying to grow RNA crystals and thus unlock some of their mysteries. Although scientists are well along the path of cracking the code of DNA, they’re far from understanding RNA, a substance copied from the DNA molecule and the one that actually puts together the structures that breathe life into us. Says the 35-year-old biologist: “I get chills up and down my spine when I think about the possibility of getting insights into the origin of life.”

PLANET FINDER

B. Scott Gaudi, 26, became hooked on astronomy in the second grade when he memorized the names of all the planets in our solar system. Today, at the Institute for Advanced Study in Princeton, Gaudi has many more names to memorize as he searches for planets outside our solar system. So far, astronomers have evidence of 44 other planets, all relatively close to us in our galaxy. Most discovered so far are nothing much like Earth because the techniques used to find them work best at spotting bodies far larger than our planet. Gaudi theorizes that the key to finding smaller planets is to watch for admittedly rare events, like the transit of a small planet across a star, or the bending of light, called gravitational lensing, that occurs when a star and its orbiting planet cross in front of a more distant star. Meanwhile, Gaudi will be watching—with optimism. He anticipates the next two decades will yield a startling census of planets and a more reliable sense of whether we really are alone in the cosmos.

BLACK-HOLE SEER

Andrea Ghez is about to see what by definition cannot be seen. Through careful study of the sky, she has assembled the best evidence yet for the existence of a supermassive black hole at the center of our galaxy. Stars nearby appear to be orbiting something huge yet imperceptible, with gravity so strong that it sucks in all light, thus making it invisible. These supermassive black holes would be one million to one billion times bigger than the smaller stellar black holes that have already been proven to exist. If Ghez, 35, a professor of physics and astronomy at the University of California at Los Angeles, succeeds in detecting the monstrous black holes, she’ll start exploring their relationship to the birth of galaxies.

PARTICLE MATCHMAKER

In the particle world that 20th-century physics has defined, like charges repel and opposite charges attract, always and forever. So what was physicist **David G. Grier** seeing when two enormous—and thus strongly charged—identical molecules he was studying started pulling toward each other? Were the laws of physics breaking down? Not exactly. "Current theories treat electrons and other particles as independent," says the 38-year-old University of Chicago associate professor. But sometimes particles act cooperatively, and their group behavior, as with Grier's molecules, can seemingly flout physical laws. All of which makes for nice job security. "Looking at the inadequacy of current theory," Grier says, opens a whole new world for physicists.

COLLISION QUEEN

Growing up in South Korea, **Young-Kee Kim** excelled at almost every subject in school, but she fell in love with math. Today, at age 37, she is a world leader in experimental particle physics. An associate professor at the University of California at Berkeley, Kim has made it her goal to understand the origins of mass. Like many particle physicists, she bemoans the loss of the U.S. supercollider once under construction in Texas, a 54-mile-long machine that would have made her work much easier. Congress cut off funds for the project in 1993. Rather than wait for one to be built, she is making do with the existing collider at the U.S. Department of Energy's Fermilab. With it, she's provided a more precise measure of the subatomic particle "W vector boson." Now her energies are aimed at proving the existence of the elusive Higgs particle, which scientists believe is the basis of mass.

ROCKET WOMAN

As a child in a one-gas-station town in Michigan, **Diane Linda Linne** read voraciously, watched *Star Trek*, and sometimes played with water rockets. Today, she's an engineer at the NASA Glenn Research Center in Ohio and rockets are an everyday part of her life, but her fun has more purpose: figuring out how to build a gas station on Mars. Long-distance space travel creates a fueling problem, explains Linne, 36. If scientists pack a rocket with enough fuel for a manned voyage to Mars and back, the engines would have to be made bigger, which would make them heavier, thus requiring more fuel, which in turn would require bigger rockets, and so on. Linne's solution to this catch-22 is to build a rocket powered by carbon monoxide, which can be obtained by splitting apart carbon dioxide, a gas that happens to be abundant in Mars's atmosphere. If she's successful, future space travelers will simply plot their course and fill 'er up at the Red Pump.

QUANTUM LEAPER

Everyday life outside the lab is predictable and consistent for **Hideo Mabuchi.** When he kicks a soccer ball, he can watch it soar from his foot to the goal. When he holds a bottle of wine up to the light, he can see if it's empty or full. But life at the smallest scale of the universe is very different. Electrons don't seem to follow a discernible path, like a soccer ball that leaves your foot and then appears in the goal net, leaving no trace of the route between the two. At that tiny scale, where quantum physics operates, a wine bottle could be full and empty at the same time. Yet, somehow, the large-scale, clockwork-precise world we inhabit emerges from this quantum foam. How? No one knows, but Mabuchi, 29, an assistant professor of physics at Caltech, intends to find out. One approach he's taking is to build something no one really understands how to build: a quantum computer. It theoretically could use the ability of a quantum particle to spin two ways at once to compute information. Such a computer, Mabuchi says, could shed light on the fuzzy interface between our everyday world and life at a subatomic level. Stay tuned.

STRINGS PLAYER

Whether he's looking up at the stars or down at his coffee cup, Harvard University professor of physics **Juan Maldacena,** 32, imagines strings—tiny strings that vibrate to form the electrons in his coffee cup as well as those in the stars. No one has actually seen such a string, but they appear readily in the equations of an army of physicists like Maldacena who are searching for what has come to be known as "the final theory." The fact that we seem to need both quantum theory and relativity theory to explain the variety of particles and forces we've discovered in our universe bothers many physicists: Shouldn't there be just one underlying principle? Moreover, there are difficulties rectifying the equations of quantum mechanics and relativity under extreme conditions, such as those found in a black hole or at the beginning of the universe. The tiny strings might be a better explanation of everything, from the beginnings of time to coffee cups. The Argentine-born Maldacena has recently made a major contribution to string theory by showing that two mathematical pathways other researchers have been pursuing separately are actually similar and interchangeable.

CANCER SHAPE-SHIFTER

Cells are an egalitarian and selfless bunch, willing to do whatever they're commanded to do for the good of the body around them. Through evolution, they have developed a mechanism for knowing whether the body needs them to multiply and grow, or kill themselves. But the genes that run such delicate machinery, says researcher **Nikola P. Pavletich,** 34, at Memorial Sloan-Kettering Cancer Center, are subject to damage from environmental toxins as well as normal cellular processes. In healthy cells, a crack team of proteins maintains DNA so that the cell responds properly to its instructions. But if these proteins themselves get altered, the repair work can get shoddy. Then a cell might multiply instead of dying, thereby spurring cancer. Pavletich searches for just such malignant alterations in his lab by growing proteins

LLOYD DEGRANE (DAVID G. GRIER); KRIS SNIBBE (JUAN MALDACENA); ROBERT LISAK (NIKOLA P. PAVLETICH)

"Apes' minds are not just duller, less-talkative versions of our own. They are different in very peculiar and interesting ways"

into crystals and then analyzing their three-dimensional structure. Sometimes all it takes to turn a cell cancerous is for a single molecule to change its shape, he has discovered. If he can change it back, he could be a giant step closer to a cancer cure.

CHIMPS' CHUM

If apes can count, use tools, and learn sign language like humans, can they think like us too? If so, why don't they study us the way we study them? Those are the kind of questions that fascinate **Daniel Povinelli,** 36, a comparative psychologist at the University of Louisiana. "Apes' minds are not just duller, less-talkative versions of our own," he says. "They are different in very peculiar and interesting ways." For nine years, Povinelli has studied seven chimps in his Lafayette lab, using tools, mirrors, and nonverbal games to learn the architecture of chimp thought. His conclusion: Abstract conceptualizing is beyond a chimp's ken. The reason apes don't study humans to find out how we think, he says, is because they do not think about thinking. And that may ultimately be the greatest difference between us and them. The most important concept underlying Povinelli's work is that it's not really about the apes. Only by studying animals similar to us, says Povinelli, will we come to understand ourselves better. His real goal is to discover what it means to be human.

PLANT WIZARD

Growing up in a Colorado farming community, **Daphne Preuss** took every opportunity to escape from the work. She was too busy tracking grasshoppers through the surrounding plains or poring over biographies of famous inventors. She still remembers reading of Thomas Edison—about his "invention factory" and how he tested thousands of filament fibers before coming up with a workable lightbulb—and the lessons she took from his efforts: Be imaginative, practical, and persistent. Now she has invented something remarkable of her own. In a daring feat uniting biology and technology, the 37-year-old assistant professor of molecular genetics at the University of Chicago has created entirely new plant chromosomes. While current genetic engineering relies on inserting single genes into natural chromosomes, Preuss is aiming to place multiple genes into artificial chromosomes. Instead of inscribing a single word into a plant's encyclopedia of genetic information, she hopes to compose her own separate volume. In a university lab the first crop of plants from her tinkering are growing each day, and Preuss watches to see what specific properties each will deliver. Within 20 years, she predicts, scientists will be able to construct artificial chromosomes to create plants that not only resist insects, fungi, and droughts—as they do already—but that also make vitamins, pharmaceuticals, and biodegradable plastics.

WAVE RIDER

Mathematician **Terry Tao,** at 25 the youngest full professor the University of California at Los Angeles has employed in decades, lives in a world that has no connection to reality. Put in the simplest of terms, he studies how to "control the number of times a wave focuses at a point," and readily admits this abstract mathematical concept is complicated and "very theoretical." Still, he believes the ultimate reverberations from his research are simply not foreseeable. Descartes, he notes, had no idea that his calculus would one day make predicting the orbit of a satellite possible. "The work of mathematicians from even a millennium ago is still routinely used," Tao observes, "and the stuff that we do today is going to be part of the math of the future."

TEMBLOR MAN

Several months ago, Dutch-born theoretical seismologist **Jereon Tromp**, 34, traded his job at Harvard for one at Caltech so he could be closer to the action. Many seismologists focus on what past earthquakes did to the surface of Earth—what moved, where, and by how much. Tromp goes further, using the data to derive complex mathematical equations and rules that he hopes will express how the earth beneath his feet might behave during the next earthquake. With enough data, he says, he might even be able to predict how individual neighborhoods in a city will shake in a specific type of earthquake. That sort of early-warning map would give building engineers, city planners, and rescue teams what they really need to know to prevent tragedy.

CLONE MASTER

Scientists had been trying to clone mice for 16 years when, in 1997, Japanese-born biologist **Teruhiko Wakayama** proposed the novel idea of using unfertilized rather than fertilized eggs in the process. Wakayama says he didn't believe the unfertilized eggs would create a clone. Nor did senior scientists—cloning is an incredibly difficult technology dependent on all the complexities of life itself. Wakayama says he simply hoped that data from a different approach might be helpful. "My interest is solely to find mechanisms in biology to explain why living things are alive," says the 33-year-old research assistant professor at Rockefeller University in New York City. "I am not interested in making another animal." To everyone's surprise, the technique succeeded. Wakayama's colleague, Tony Perry, thinks this biologist triumphed where others failed because "he has an incredible insight . . . he can see what will work." Perry contends Wakayama was humble when he said he had doubts about trying to clone a mouse from an unfertilized egg: "He knew it would work."

{Back to the future.}

BIO CROPS

that could win blue ribbons in twenty years
if we don't watch out

TEXT & ILLUSTRATIONS
BY BRUCE McCALL

Killer bees, injected with Rottweiler genes to emit a tiny bark that chases insect pests from crops? Don't bet against it

STAGED INSIDE THE WORLD'S LARGEST BUTTERNUT squash, itself a triumph of advanced biotechnology, Biotexpo 2020 literally dwarfed last year's bio-bombshell of giant bonsai trees with a cornucopia of innovations—heralding a future that will be, in one bio-booster's words, "all about tomorrow."

The bio-geniuses at SweetSciences Inc. titillated show attendees with their "Perpetua" chewing gum, a super-secret formula reportedly combining the fundamental genetic codes of sugar, peppermint, and latex rubber for locked-in flavor and ruminant pleasure limited strictly by the durability of the chewer's jawbone.

But that's not the only surprise about to spring from the soil. Anyone for decorator zucchini? Bio-Martha Labs, a division of Martha Stewart Inc., has just bio-designed a whole new line of that once-dowdy fruit in polka-dot, plaid, and Harris tweed, turning any ho-hum 40 acres into a tasteful riot of colors and patterns.

Meanwhile, a word to the biotechnologically wise: Watch Japan! A sensation of Biotexpo 2020, Kakajumi's "cotton-candy milkweed" prototype pod can launch 20,000 feathery spoors to drift with the breeze and be plucked from the air as sugary treats. Only the public-health technicality of treating thousands of sugar-nauseated schoolchildren seems to stand in the way of prompt commercial production.

And how's this for expanding biotechnology's borders? Nipponix BioSolutions introduced its intriguing new "Katch-a-Karp" flashing fish, radiating an all-organic, police-intensity pulsing red light visible underwater from a boat or dock as far as 100 yards away. Available so far in carp and catfish only—but self-illuminating swordfish are only months away.

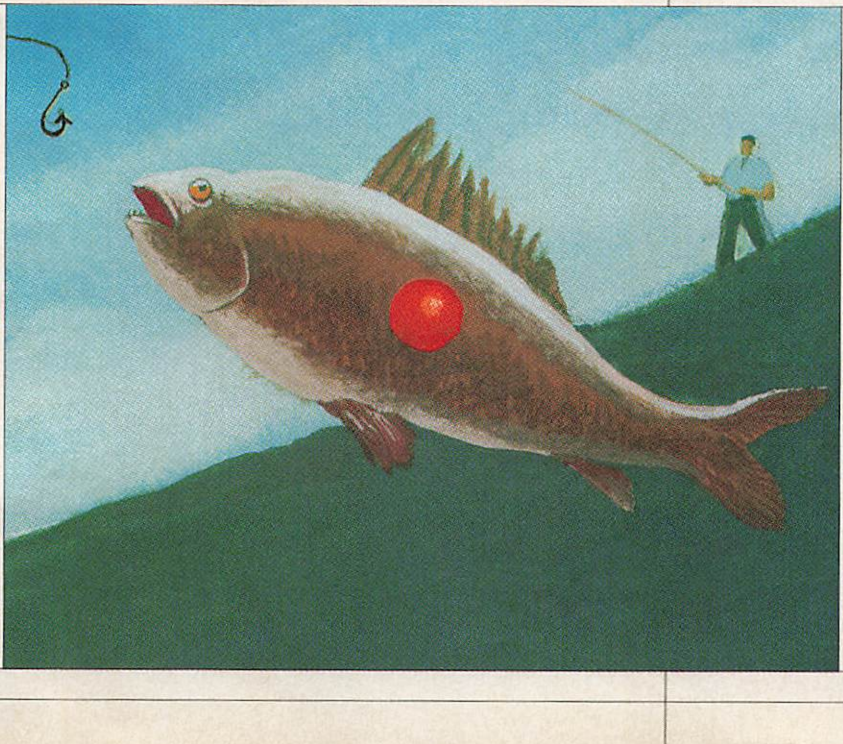
Rocking Big Poultry at Biotexpo 2020 was a live demonstration of the first-generation flock of biotechnologically engineered suicidal turkeys. The smart birds' foolproof knack for doing away with themselves punctually in the second week of November is expected to slash Thanksgiving turkey processing costs by half—without harming their succulent flavor or carving ease.

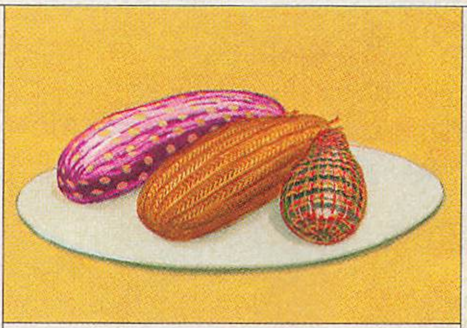
South American killer bees, injected with Rottweiler genes to emit a fierce if tiny bark and chase away insect pests from precious crops? Don't bet against it, bio-beekeepers say, once a stout enough leash is developed.

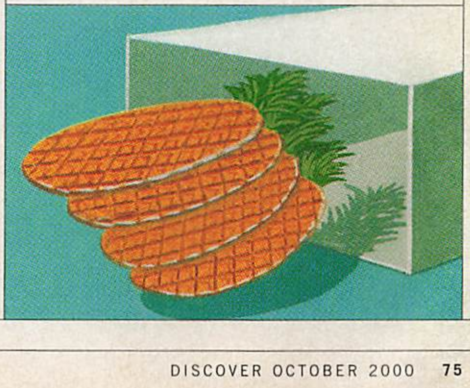
Certain advances may, alas, forever elude biotechnology's grasp. The fusion of Kentucky sour-mash bourbon and Chinese silkworms, for example, has time and again fizzled, leaving the ancient vision of the lickable 100-proof necktie only a dream. And self-packing strawberries, bio-designed to include genetic material from migrant pickers—promising 15-second fill times per six-quart basket—have run smack into a brick wall of bio-legal resistance. The ACLU's lawsuit defending strawberries against low wages, long working hours, and OSHA safety violations could stymie production indefinitely.

What are biotechnology's outer limits? After this Biotexpo, one can only wonder.

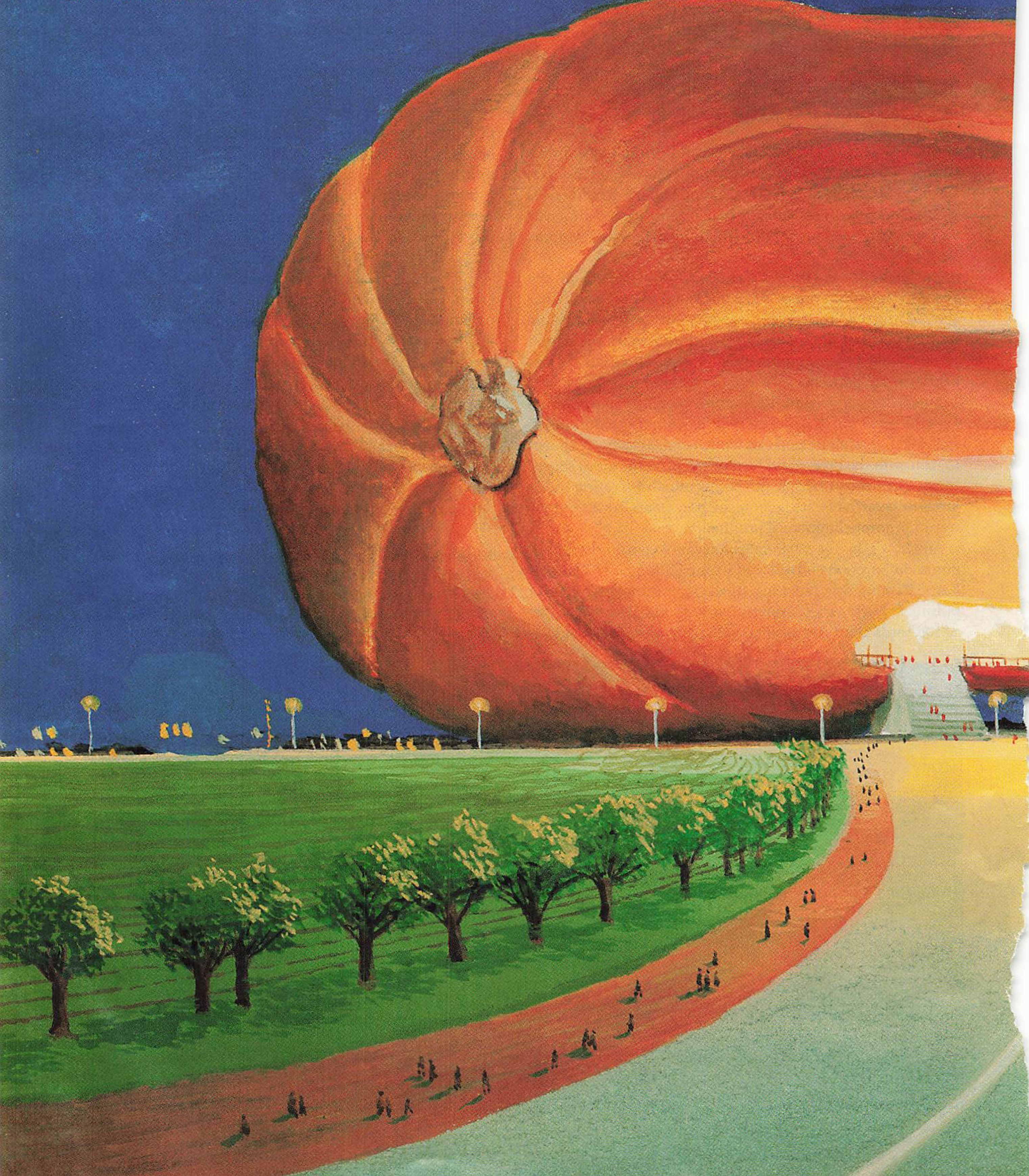
Below left: Katch-A-Karp's pulsing red light is visible underwater for 100-percent guess-free fishing. Below right: zucchini from Bio-Martha Labs are decorator approved. Bottom right: Pizza-flat pineapples are bioengineered to laugh at those bulky-shipment blues, while research into collapsible avocados is proceeding apace.

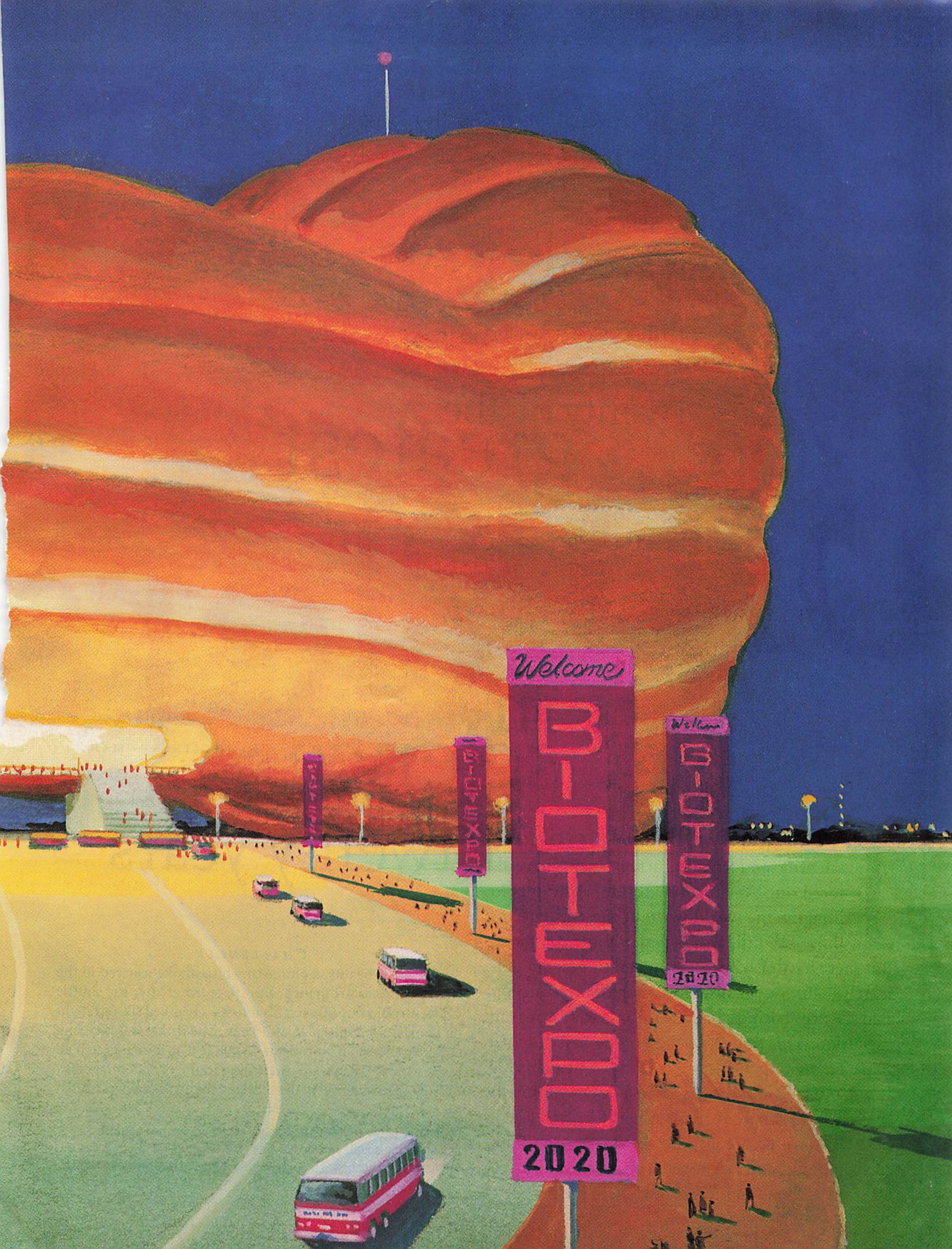






More than 200 gargantuan near-misses were seeded and grown before bio-architects finally succeeded in creating an arena-sized squash that was symmetrical, structurally sound, and ripe enough to house Biotexpo 2020.




Welcome
BIOTEXPO
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Welcome
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BIOTEXPO

{What were they thinking?}

Twenty of the greatest blunders in science in the last twenty years

BY JUDITH NEWMAN

IN THE LAST TWO DECADES, GLORIOUS scientific and technical achievements have altered our lives forever. Try, for example, to imagine the world without the existence of those two little words *personal* and *computer*. But there have also been—how can this be put delicately?—blunders. Some were errors in concept: Bad science chasing a bad idea. Some were errors in execution: *This would have worked so well if only it hadn't blown up.* Others were cases of deliberate fraud, out-and-out hoaxes, or just dopey moments that made us laugh. Perhaps Albert Einstein said it best: "Two things are infinite: the universe and human stupidity, and I'm not sure about the universe."

CHALLENGER

Surreal in its beauty, a plume of white smoke ushered in the end of America's romance with space travel after the shuttle *Challenger* blew up 73 seconds into its scheduled six-day flight on January 28, 1986, at 11:39:13 a.m. The rocket was traveling at Mach 1.92 at an altitude of 46,000 feet as it incinerated all seven astronauts aboard. According to the presidential commission that investigated the accident, the explosion was caused

On the eve of the *Challenger* disaster, engineers warned against launching the shuttle in cold weather. The temperature at liftoff was 36 degrees Fahrenheit, 15 degrees colder than at any previous launch.

AP PHOTO/NASA

by the failure of an O-ring seal in the joint between the two lower segments of the right-hand solid-rocket booster. This failure permitted a jet of white-hot gases to ignite the liquid fuel of the external tank. The O-ring was known to fail in cold temperatures, but the launch had been delayed five times.

Darsee and Slutsky and Fraud, Oh My!

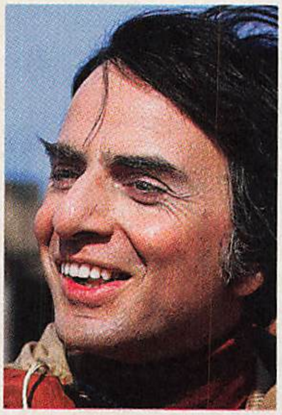
Following the "greed is good" mantra of the 1980s, some scientists could not resist shortcuts. "The psychological profile of these people is interesting," says Mario Biagioli, a professor of the history of science at Harvard University. "You usually get B-plus, A-minus scientists who get into hyperproduction mode." Take, for example, former Harvard researcher John Darsee. In 1981 he was found to be faking data in a heart study. Eventually investigators at the National Institutes of Health discovered that data for most of his 100 published studies had been fabricated. Or take the case of cardiac-radiology specialist Robert Slutsky, who in 1985 resigned from the University of California at San Diego School of Medicine after colleagues began to wonder how he turned out a new research article every 10 days. University investigators concluded he had altered data and lied about the methods he used. To establish verisimilitude, Slutsky often persuaded scientists more prominent than he to put their names on his articles.

The Debendox Debacle

William McBride, an Australian obstetrician, was hailed as a whistle-blowing visionary in 1961 when he sounded a warning about the dangers of thalidomide, a sedative prescribed for anxiety and morning sickness. In a letter to the journal *The Lancet,* McBride suggested that the drug was causing infants to be born with severe limb deformities. Although McBride's hypothesis was based on limited anecdotal observations, subsequent studies proved him right. Thalidomide was removed from the market, and the drug became almost synonymous with pharmaceutical malfeasance. Two decades later, in 1982, McBride published a report about a morning-sickness drug called Debendox that, he claimed, clearly caused birth defects in rabbits. Merrell Dow took the drug off the market amid an avalanche of lawsuits. But there was a problem. McBride had altered data in research carried out by assistants. The results showed Debendox had no ill effects. After years of investigation, McBride was found guilty of scientific fraud in 1993 by a medical tribunal.

Nuclear Winter of Our Discontent

In 1983, astronomer Carl Sagan coauthored an article in *Science* that shook the world: "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions" warned that nuclear war could send a giant cloud of dust into the atmosphere that would cover the globe, blocking sunlight and invoking a climatic change similar to that which might have ended the existence of dinosaurs. Skeptical atmospheric scientists argued that Sagan's model ignored a variety of factors, including the fact that the dust would have to reach the highest levels of the atmosphere not to be dissipated by rainfall. In a 1990 article in *Science,* Sagan and his original coauthors admitted that their initial temperature estimates were wrong. They concluded that an all-out nuclear war could reduce average temperatures at most by 36 degrees Fahrenheit in northern climes. The chilling effect, in other words, would be more of a nuclear autumn.



Carl Sagan predicted that clouds of soot from Kuwaiti oil fires following the 1991 Gulf War would affect global climate and validate his nuclear-winter theory. He was wrong.

Unwed forty-something women who believed a 1980s report that they were less likely to marry than "be killed by a terrorist" were not alone in singing bridal blues. Forty percent of 2,075 Moonie couples wed en masse in New York in 1982 reportedly divorced within three years.

Piltdown Chicken

The finding was initially trumpeted as the missing link that proved birds evolved from dinosaurs. In 1999 a fossil smuggled out of China allegedly showing a dinosaur with birdlike plumage was displayed triumphantly at the National Geographic Society and written up in the society's November magazine. Paleontologists were abuzz. Unfortunately, like the hominid skull with an ape jaw discovered in the Piltdown quarries of England in 1912, the whole thing turned out to be a hoax. The fossil apparently was the flight of fancy of a Chinese farmer who had rigged together bird bits and a meat-eater's tail.

Statistics for Dummies

Shocking factoids based on half-baked interpretations of scientific data have been foisted on the public at an alarming rate during the past 20 years. Take the "spinsters beware" theme that gained currency in 1986. Summarizing a study on women and marriage by two Yale sociologists and a Harvard economist, several news agencies reported that single women at 35

LEFT: PHOTO RESEARCHERS; RIGHT: DAVID M. GROSSMAN/PHOTO RESEARCHERS

had only a 5 percent chance of ever marrying, and unmarried women at 40 were "more likely to be killed by a terrorist." Never mind the fact that in analyzing data from the 70,000 households the authors of the original study had not looked into what percentage of the over-30 women had made a conscious choice to put off marriage. Indeed, U.S. Census Bureau statistician Jeanne Moorman's follow-up projections indicate that of unmarried women ages 30 to 34, 54 percent will marry; of those ages 35 to 39, 37 percent will marry; and of those ages 40 to 44, 24 percent will marry.

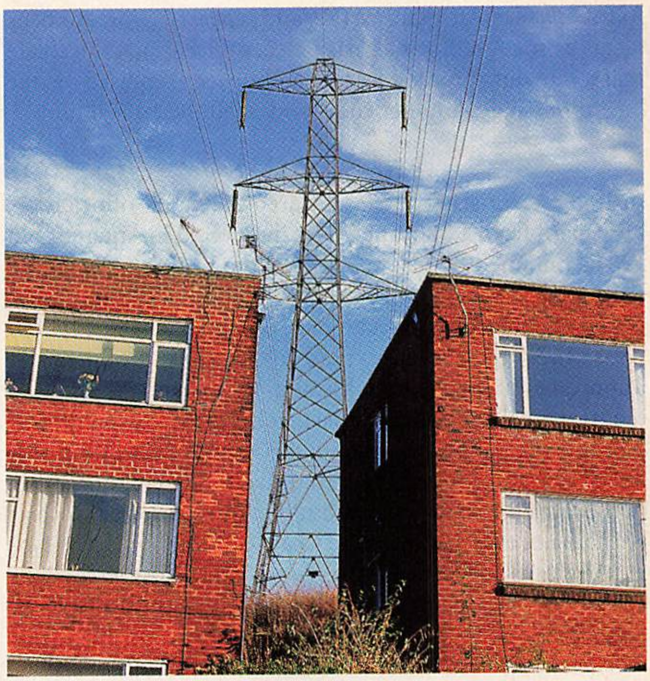
Very Cold Fusion

At the University of Utah in 1989, chemists Stanley Pons and Martin Fleischmann announced that the world's energy problems had been solved. They claimed to have created nuclear fusion on a tabletop by electrolyzing deuterium oxide—heavy water—using electrodes made of palladium and platinum. Deuterium is a naturally occurring stable isotope of hydrogen; its nucleus contains a neutron in addition to the single proton found in the nucleus of ordinary hydrogen. According to the chemists, the deuterium nuclei were squeezed so closely together in the palladium cathode that they fused, releasing energy. As Robert Park, professor of physics at the University of Maryland and author of *Voodoo Science* puts it, "Basically if what Fleischmann and Pons said was true, they had duplicated the source of the sun's energy in a test tube." The problem is, no other scientists have been able to reproduce their results—and not for lack of trying. "There's always some guy willing to say, 'OK, we found something that works, but it only works once in a while,' or 'We're not going to show it to you, because we're worried you'll steal our patent rights,'" says Marc Abrahams, editor of *Annals of Improbable Research.*

Chernobyl

April 26, 1986, was the day Soviet nuclear experts learned the true meaning of the word *oops.* During a test of one of Chernobyl's four reactors, they turned off the backup cooling system and used only eight boron-carbide rods to control the rate of fission instead of the 15 rods required as standard operating procedure. A runaway chain reaction blew the steel and concrete lid off the reactor and created a fireball, releasing 100 times more radiation than did the Hiroshima and Nagasaki bombs combined. Some 4,300 people eventually died as a result, and more than 70,000 were permanently disabled.

A recent United Nations assessment of the Chernobyl disaster warned that the full impact of radiation exposure on 600,000 emergency workers will not be known until the year 2016 at the earliest.



Often power lines are concentrated in areas that are poor, congested, and polluted. Such conditions may account for a slight statistical association between living near power lines and childhood leukemia.

LEFT: AFP/CORBIS; RIGHT: MARTIN BONG/SPL/PHOTO RESEARCHERS

Currents That Don't Kill

The Clinton administration estimates that American taxpayers have paid $25 billion to determine that power lines don't do anything more deadly than deliver power. In 1989, Paul Brodeur published a series of articles in *The New Yorker* raising the possibility of a link between electromagnetic fields and cancer. Eight years later, after several enormous epidemiological studies in Canada, Britain, and the United States, the danger was completely discounted. "All known cancer-inducing agents act by breaking chemical bonds in DNA," says Robert Park. "The amount of photon energy it takes is an ultraviolet wavelength. So any wavelength that is longer cannot break chemical bonds. Visible light does not cause cancer. Infrared light is still longer, radio waves longer still. Power-line fields are preposterous. The wavelength is in miles."

Mars Meltdowns

The "better, faster, cheaper" mantra adopted by NASA in 1992 might be reinterpreted today as "you get what you pay for." In September 1999, the $125-million *Mars Climate Orbiter* plunged to oblivion near Mars. NASA officials were using the metric newton to guide the spacecraft. That was unfortunate, because Lockheed-Martin engineered the *Orbiter* to be guided in the English units of poundals. In December, the $185-million

Mars Polar Lander went AWOL, and repeated efforts to contact it by space radio antennas failed. Officials now speculate that a signaling problem in the landing legs—caused by one line of missing computer code—doomed the *Lander*.

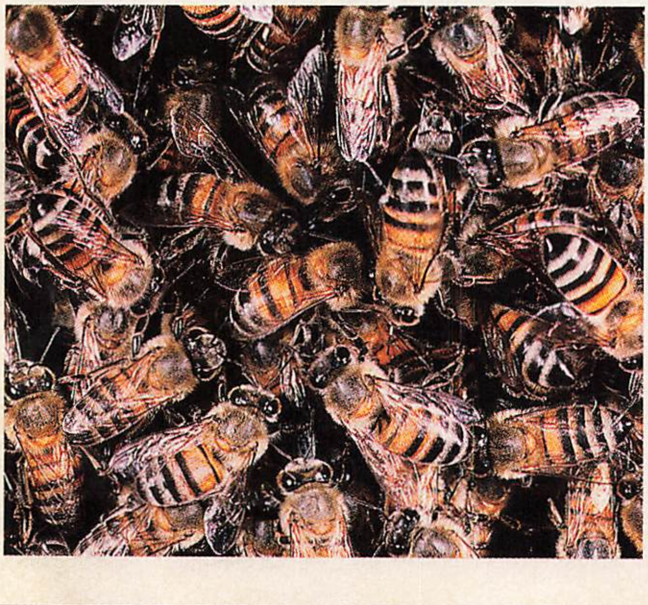
ROCK OF LIFE

In 1996, scientists at NASA declared that a 6.3-ounce rock, broken off from a Mars meteorite discovered in Antarctica in 1984, contained flecks of chemical compounds—polycyclic aromatic hydrocarbons, magnetite, and iron sulfide—that suggested the existence of bacteria on the Red Planet 3.6 billion years ago. "August 7, 1996, could go down as one of the most important dates in human history," intoned one newspaper report. But within two years the theory began to crack. Traces of amino acids found in the rock, crucial to life, were also found in the surrounding Antarctic ice. More damning, other non-Martian rocks—rocks from the moon, where it is clear life does not exist—showed the same "evidence" of life. By November 1998 an article in *Science* declared "most researchers agree that the case for life on Mars is shakier than ever."

ALL ABUZZ

Sometimes mistakes that were made decades ago take a while to make the force of their foolishness felt. Consider the case of killer bees. In the 1950s, Brazilian geneticists crossbred mild-mannered European honeybees with their more aggressive, territorial cousins from Africa, reasoning that the Africanized bees would be better suited than their European counterparts to warmer South American climes. They were too right. Before the aggression could be bred out of the resulting cross, the buggers got away, and some immediately headed north. In 1990 the first Africanized honeybees were discovered in Texas. Since that time they've gradually spread to New Mexico, Arizona, California, and in 1999, to Nevada.

While the vision of marauding swarms memorialized in the 1978 film *The Bees* hasn't materialized, at least six people in the United States have died since 1993 from multiple stings of Africanized honeybees.



Gonorrhea, once easily cured with penicillin or tetracycline, now resists all but the most expensive antibiotics. Left untreated in many poor countries, the disease is helping fuel the spread of AIDS.

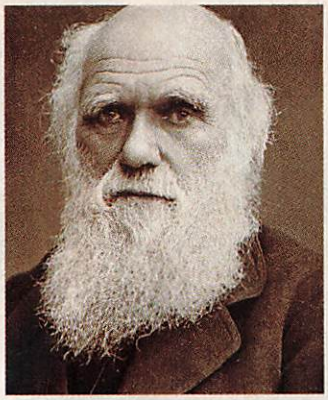
HERE THEY COME TO SAVE THE DAY

Indeed, antibiotics have been the Mighty Mouse of medicine. Since the discovery of penicillin in 1928, it seemed there were few bacteria that antibiotics couldn't destroy handily. At the turn of the last century, the average life expectancy was 47. Thanks partly to a decline in bacterial diseases like tuberculosis, dysentery, and gonorrhea, life expectancy in the United States has risen to 76 today. Unfortunately, doctors did not take seriously the consequences of promiscuous antibiotic use. Physicians have long been generous in prescribing antibiotics for minor ailments, even for viral infections like the common cold. Moreover, even when antibiotics were warranted, patients were not sufficiently warned about the dangers of not taking the drugs for the full course of treatment. When the symptoms of their infection abated, patients often threw away their pills, allowing the bacteria that had not been killed off to mutate. Now there are whole categories of antibiotics that no longer work. And there are some potentially deadly bacterial diseases, including tuberculosis, that can only be beaten by one or two of the strongest, most expensive antibiotics.

THE SKY IS FALLING AGAIN

Um, never mind. On March 12, 1998, on the front page of *The New York Times,* a headline read: "Asteroid Is Expected to Make a Pass Close to Earth in 2028." Brian G. Marsden, director of the Central Bureau for Astronomical Telegrams at the Smithsonian Astrophysical Observatory, predicted that on October 26, 2028, an asteroid about a mile in diameter would come within 30,000 miles of Earth. That's within spitting distance, spacewise, which evoked comparisons to the asteroid that crashed on the Yucatán peninsula 65 million years ago, allegedly wiping out all the dinosaurs. "When you first discover a comet, or any kind of body, you start measuring its position," notes Robert Park. "From that you extract its trajectory. The more measurements you make, the more accurate your trajectory gets." Marsden issued his warnings based on very early trajectory measurements. Now he anticipates the asteroid will pass Earth at a safe distance of 600,000 miles.

LEFT: SCOTT CAMAZINE/PHOTO RESEARCHERS; RIGHT: JAMES KING-HOLMES/SPL/PHOTO RESEARCHERS



Charles Darwin was dubbed "the Abraham of scientific men" by British physicist John Tyndall.

Evolution? What's That?

In 1995, it became official: Colorado students would not be tested on evolution, Charles Darwin's theory that, through an endless series of genetic mutations, we all developed from single-celled organisms. "I believe in divine creation," said Clair Orr, Colorado's chairman of the state's board of education. Colorado is not alone. Kansas removed evolutionary theory from its tests in 1999. Mississippi and Tennessee do not teach the subject at all, and curricula in Florida and South Carolina touch on it only lightly. Given the trend of treating all theories of how we got here as equal, Marc Abrahams, of *Annals of Improbable Research,* has a suggestion: Why not teach the theory of Chonosuke Okamura, a Japanese paleontologist who became convinced that patterns of water seepage in rocks were "mini-fossils" and that life was descended from mini-horses, mini-cows, and mini-dragons. "It's kind of like forming an evolutionary theory out of cloud formations," says Abrahams.

Fen-phen Fiasco

In the early 1990s Michael Weintraub, a researcher at the University of Rochester, concluded that a combination of two nonaddictive drugs that had been around for years—phentermine, a stimulant, and fenfluramine, an appetite suppressant—could be used for the long-term control of obesity. The fen-phen diet craze was born. Physicians began giving the drug combination off-label to patients who wanted to lose as little as 10 to 15 pounds. In the meantime, an August 1996 report in *The New England Journal of Medicine* linked the use of fen-phen for more than three months to a 23-fold increased risk of developing primary pulmonary hypertension, a fatal lung disorder. Subsequent studies revealed that prolonged use of fenfluramine could cause heart-valve defects. By September 1997, the Food and Drug Administration signaled the demise of fen-phen by ordering that fenfluramine be taken off the market. It is estimated that between 1.2 million and 4.7 million Americans were exposed to the drug combination.

To Be or Not to Be, Thanks to MTBE

It was intended to solve a pollution problem. Instead, it may be the cause of one of the most serious pollution problems of our time. MTBE, or methyl tertiary butyl ether, is a gasoline additive that came into use in the late 1970s during the phase-out of alkyl lead additives. It helps gasoline burn more efficiently and cuts down on air pollutants. It also happens to be highly water-soluble and has a nasty tendency to leak from underground storage tanks at gas stations. In California, MTBE contamination has forced water suppliers to shut down wells in many counties. A recent study by the U.S. Geological Survey found MTBE in 14 percent of all urban drinking water wells it sampled. In March 1999, the Clinton administration announced a ban on the additive. Meanwhile, there appears to be no cost-effective way to remove it from drinking water.

Earth to Iridium

The award for "Most Expensive Piece of Immediately Obsolete Technology" goes to Iridium, a communications company that 10 years ago promised crystal-clear cellular phone service anywhere on the planet. Sixty-six satellites were launched at a cost of $5 billion. "The phones were bulky. They cost $3,000. A call cost several dollars per minute, and the system didn't work indoors," says Richard Kadrey, a founder of Dead Media Project, a Web-site collection of failed media and technology. "Most people simply don't need to call Dakar at a moment's notice. In fact, the number of people who do is so small that it is probably dwarfed by the number of people who really need to talk to aliens." In 1999, Iridium took its place among the 20 largest bankruptcies in history.

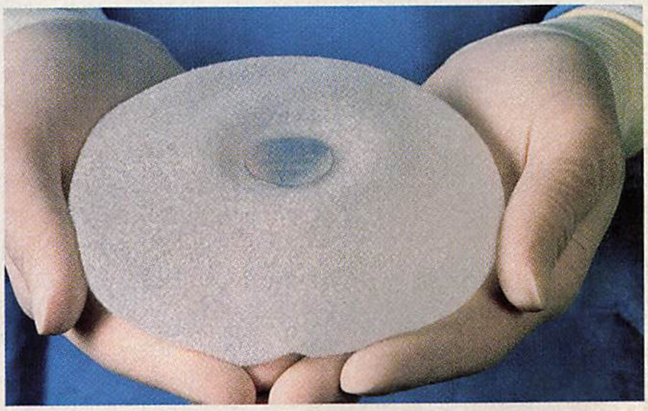
Chest Say No to Silicone Implants

Pamela Anderson had them taken out. So did Jenny Jones. They needn't have bothered, according to an independent panel of medical experts. Never mind that lawsuits over the implants bankrupted Dow Corning, a multibillion-dollar company. The medical panel reported in 1998 that there is no greater incidence of immune-system abnormalities among women with breast implants than there is in the general population. In the end the science didn't fail us; the lawyers did.

Y2K

It all got fixed before it could happen, but at a cost of $100 billion. Thanks to purposeful programming, computers were likely to read the year code "00" as 1900 instead of 2000. So we were treated to an entire year of talking heads ranting on about doomsday scenarios, including a world where airplanes would drop out of the sky and banks would register your portfolio value as zero. And some people don't have to buy canned goods for at least a year. All we can say is: Thank you, Bill Gates. ☒

Some women suffered inflammation from breast implants, but in 1998 four scientists appointed by a federal court concluded there was no evidence that silicone in the implants causes systemic disease.



LEFT: POPPERFOTO/ARCHIVE PHOTOS; RIGHT: PHOTO RESEARCHERS

{Swept away.}

Twenty things that will be obsolete in twenty years

BY ERIC HASELTINE

PHOTOGRAPHS BY MARGARET SALMON AND DEAN WIAND

On a flight from Tokyo recently, my gaze wandered from the computer sitting in my lap to the Pacific 20,000 feet below. As we descended toward Los Angeles, I watched the blue ripples relentlessly marching toward a distant shore. Suddenly I realized it would be possible to calculate from the waves' direction and velocity not only where they would end up but when they would get there. In a sense, I could predict their future. Turning back to my computer, I marveled at how quickly it had become an essential appendage, and it occurred to me that the waves below were not all that different from the waves of technological change that sweep over us. Like waves at sea, waves of technology are always out there somewhere, relentlessly heading for an impact. And they can be detected while still far from shore. We even ought to be able to see them coming when they're 20 years away.

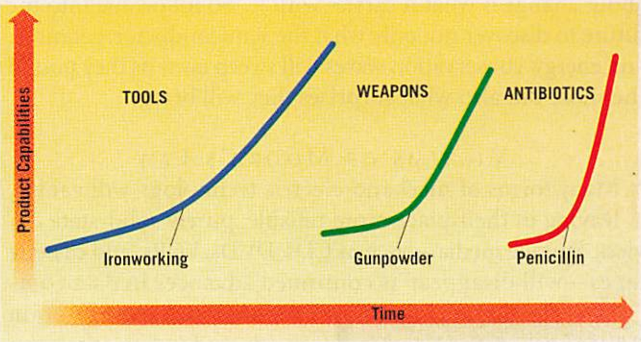
To understand what a wave of the future might look like today, I looked at past technological innovations like iron metallurgy, gunpowder, and antibiotics. I found they all began as ripples of change but soon became steep waves because whatever the discovery involved, it led quickly to extremely useful stuff. Note the abrupt steepening of the curves in the "Historic Waves of Technological Change" graph.

Today there are several waves of change still out there at sea. The first headed our way is generated by the fact that integrated circuits are shrinking in size, which tends to about double the speed of computers every 18 months or so. Moore's Law, as this curve is called, predicts that all kinds of digital devices will either perform the same job in smaller packages, or the same-sized devices will do twice as much. So in 20 years a Pentium chip will either fit in a die 1/10,000 its current size, or it will keep its size and have roughly 10,000 times its current processing power. A similar concept holds true for solid-state memory devices. RAM chips double in capacity every year and a half or so, and magnetic disk drives are on a steeper curve, doubling in performance every nine to 12 months.

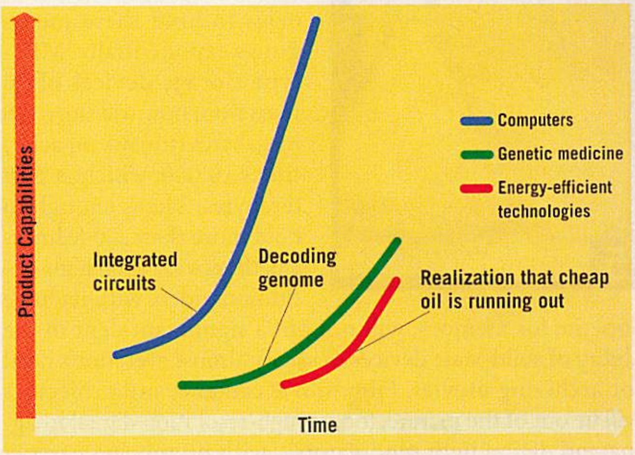
Another big "eureka!" wave headed our way formed from recent attempts to map the human genome. Just as solving a jigsaw puzzle gets progressively faster as the puzzle nears completion, a rush of gene-based therapies is likely to follow rapidly in the next two decades from unraveling the nucleotide puzzle that makes our cells do what they do. In fact, decoding our genes could be the single greatest inflection point in human history because, unlike previous discoveries that perturbed an ocean of stuff around us, genomic science could fundamentally change who we are.

Consider the "Contemporary Waves of Technological Change" graph. It indicates that computer capabilities and genetic medicine are likely to follow exponential growth curves that echo the major technology inflections preceding them, creating an array of high-performance products 20 years from now. But early in this same period, as shown in the "Projected Worldwide Oil Production" graph, half the world's known oil supply will have been used, and oil production will slide into permanent decline. This will not be an ersatz crisis like the oil embargo of the 1970s but a permanent change in the energy landscape, in which plenty of oil will still be available but not at today's prices. Shortly after the downturn in oil production and associated price increases, industrialized nations might face threatened economies, not to mention the growing geopolitical power of countries holding the world's reserves.

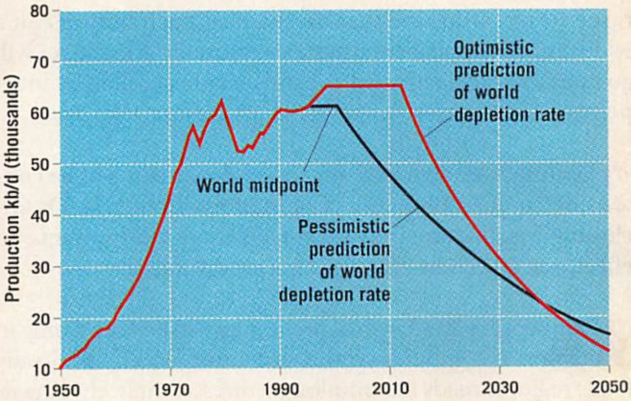
HISTORIC WAVES OF TECHNOLOGICAL CHANGE



CONTEMPORARY WAVES OF TECHNOLOGICAL CHANGE



PROJECTED WORLDWIDE OIL PRODUCTION



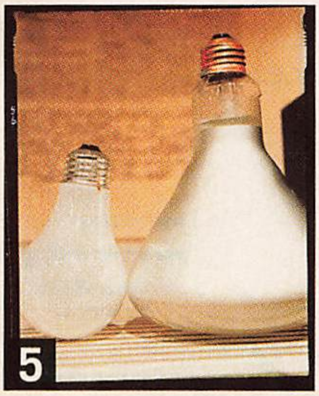
Energy-efficient innovations will arise from this crisis and alter all of our lives significantly. Indeed, this is an example of technology that must be invented to maintain the standard

Internal combustion engines have been ubiquitous since Henry Ford succeeded in making the Model T "the family horse." In 20 years they could be on the scrap heap, replaced by electric or hybrid engines.

of living we now enjoy. Perhaps the most interesting thing about change is what it carries with it. So follow me into the future to discover not only what the semiconductor, genomic, and energy-conservation waves will sweep away as they pound the shore but also what surprises they will bring.

Victims of Moore's Law

1 Many forms of mechano-electric technology will vanish, leaving in their place more reliable, purely solid-state devices. Storage media—such as CDs, DVDs, VCRs, and cassette tapes—will disappear as continued advances in data compression technology cram music and videos into even less memory space and the capacity of solid-state memories to hold these media grows exponentially. MP3-type storage devices of 20 years from now will store 128 megabytes (today's capacity) times 10,000, which is 1.28 terabytes. That's enough to hold more than 200 feature-length movies. Even high-definition video, with its huge appetite for memory, will not put a significant dent in the ability of solid-state devices to satisfy almost everyone's need for archiving movies. Film movie cameras and projectors will be out of the picture, too, as high-resolution digital imaging and digital light modulators—with no moving parts—replace their counterparts. It's a good bet that still-film cameras and slide projectors will be curiosities better suited to antique stores. Odds are that mechanical push buttons on a wide range of appliances from TV remotes to telephones will go away as voice-activated controls, made possible by inexpensive, high-performance signal processors, take over.



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2 Writing your signature on a legal document will be considered quaint because of ubiquitous biometric IDs, including iris, fingerprint, and voice-recognition systems. In effect, you'll become your own irreproducible ID.

3 Film scores played by real orchestras will be found only in archives as computer-synthesized music, which has already made major inroads into motion pictures, completely drowns out the real thing. The majority of choral music in movies will also arise from electronics, not singers.

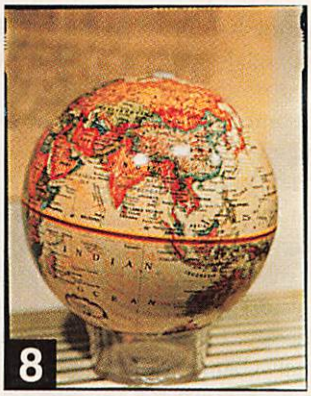
4 Nielsen ratings will be gone, because most TVs will be linked to broadband two-way network connections that tell broadcasters how many viewers are watching at any given instant. In addition, biometric ID technology could make it possible for broadcasters to find out exactly who is watching and what they do with their remotes (scary, huh?).

5 Many analog devices will vanish as more powerful digital devices replace them. Analog TVs and radios will join the vacuum tubes on the shelves of electronic surplus stores. Digital broadcasting, providing over 10 times the channel capacity of the analog spectrum, will be the norm. Digital TV and radio will also have much better quality. The market for analog cathode-ray tubes will implode as various sorts of more compact, power-efficient flat panel displays come to dominate. Ditto for incandescent lightbulbs, which will give way to much longer-lived LED lighting sources that consume little power. Analog cellular phones and phone modems will be disconnected forever as high-performance digital systems replace them. Although it would be great if mobile phone service got more reliable as a result, the likely scenario is that cellular services will be as flaky as today, only they'll move a lot more data, including video. Unfortunately, decreased reliability seems to be a pervasive side effect of progress, which explains why your PC crashes a lot more often than your TV.

6 We'll wonder why we ever patronized video, record, and software stores. Broadband connections will be a much simpler way to distribute movies, music, and software. Network distribution of content will also be considerably cheaper: no manufacturing, no middleman, and no inventory to stock.

7 Wires on headphones, even for the cheapest portable stereo devices, will be gone because low-cost radio links will replace them. It will also be hard to find anyone who holds a cell phone to his ear because it will be much more convenient to put the guts of the phone on a wrist or waist and have it wirelessly link to a small earpiece and microphone.

8 Getting lost will take real creativity in an era where an embedded GPS receiver will enable personal electronic devices such as cell phones, personal digital assistants, and wristwatches to know where they are to within a few yards.



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9 Junk mail will no longer show up. Advertisers will print their messages in your home or office using your online connection without troubling themselves with postage and printing costs. You won't call it junk mail because advertisers will know so much about you from monitoring your purchase patterns and online behaviors that the advertisements will be for items you probably will want to buy anyway. Postal meters will also be stamped out in an era in which secure remote printing of postage in homes and businesses becomes commonplace.

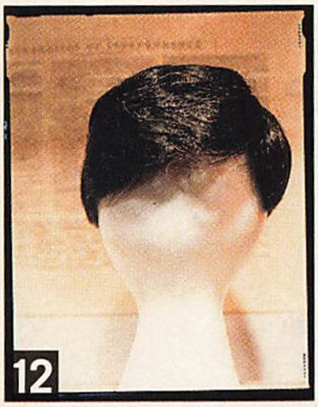
10 Stunt doubles in action-packed TV shows and motion pictures will have ridden off into the sunset because incredibly realistic computer animations of actors will be much safer and cheaper to produce. Similarly, the Screen Actors Guild probably won't have extras on its roster in 20 years.

PREVIOUS PAGE: GRAPHS BY STEVEN STANKIEWICZ; OIL PRODUCTION GRAPH (HUBBERT CURVE) ADAPTED FROM THE DATA OF COLIN J. CAMPBELL

Victims of Gene-Based Therapies

Genes express themselves by causing cells to manufacture proteins that form the building blocks of life. Various therapies will probably come on the market in the order of the complexity of these proteins, with simple therapeutic proteins (such as growth hormones) arriving first, followed by antibodies, then whole cells, and finally entire organs.

Doctors will administer these new therapies by turning genes "on" to grow therapeutic proteins, by placing healthy genes in diseased cells, or by tricking the genes of one class of cell into transforming those cells into other types of cells, which can then be used to replace diseased tissues.



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Predicting which medical treatments will be replaced by gene therapies is both easier and harder than making guesses about digital electronics. It's easier because the long clinical testing cycles of up to 10 years dictate that new drugs introduced a decade or more from now must already be in the early stages of development. It's more difficult because discoveries in biology have never obeyed the orderly laws of progress shown by engineers working with semiconductors.

11 Hemophilia medicines that now come from limited supplies of donated blood will be replaced by safe proteins synthesized outside the body or by coagulation factors produced by genetically modified cells within the body.

12 Baldness treatments will thin out dramatically as dermatologists learn how to make scalp tissue grow hair follicles. Antigraying formulas may also fade away as gene therapies restore melanin pigments to older scalps. Although genetic baldness treatments are in the very early stages of development, the revenues that could be generated from effective treatments will no doubt guarantee that significant research dollars will be focused on getting to the root of the problem.

13 These days more than 600,000 coronary bypass procedures are performed annually, but such painful and debilitating surgery will be passé when cardiologists begin to use their genetic arsenal to grow new blood vessels in place of those that are blocked. Promising early results from clinical trials of vascular endothelial growth factor 2 suggest that stimulated blood-vessel growth may be a viable treatment option both in the heart and in the limbs well before 2020.

14 Diabetics will finally be able to say good-bye to insulin injections. The better alternative: Doctors will routinely implant healthy islet of Langerhans cells into the pancreas.

15 Genetic diseases can arise from mutations of either single genes or multiple genes acting in concert. The first genetic diseases to be eliminated will most likely be the single-gene variety because doctors can more precisely target the locus of the disorder. Illnesses falling in this category include cystic fibrosis, familial hypercholesterolemia, Huntington's chorea, sickle-cell anemia, Duchenne (a form of muscular dystrophy), and Tay-Sachs disease. To some extent genetic research has already provided a type of treatment for these cases, in that individuals carrying the mutations can be identified and counseled on the risks of passing on the disorder to their offspring.

16 Immunosuppressants to prevent rejection of transplanted organs won't be needed in a world where doctors grow new organs from a patient's own tissues.

17 Chemotherapies that are toxic to both healthy and malignant cells are likely to become less important for attacking cancers when more precise gene-based treatments emerge. Techniques in development include: infecting tumors with recombinant viruses that make cancer cells vulnerable to antiviral and antibiotic agents; designing antibodies that attack cancers; and taking tumor cells out of the body, genetically altering them, and injecting them back into the body as vaccines that stimulate the immune system.

Drowned in Oil

18 Internal combustion engines won't be found on any sales lots because cars and trucks will be powered by battery-driven electric motors, hybrid gas/electric engines, or gas/fuel-cell engines. Even with improved fuel efficiency, long-haul trucking in the United States is likely to dwindle as it has in Europe, where gas prices are already high.

19 Cooling towers on industrial buildings will be eliminated because they throw off too much waste heat. They'll be replaced by natural-gas-powered absorption chillers similar to technology found on old gas refrigerators. Radiated energy will be recaptured to warm water and generate electricity.

20 Plastic wrap and many plastic utensils will be found only in landfills. Replacing plastics will be an entire family of biopolymers made from cornstarch. Some are already available but still too costly compared with compounds made from temporarily cheap petrochemicals.

13

Beyond 2020

Let's ride our wave metaphor out to sea, past the swells of Moore's Law, genomics, and oil prices to longitudes where tomorrow's tsunamis are but today's gentle undulations. In these waters we'll find disturbances arising from nanotechnology, optical computing, bionics, and nuclear fusion, giving us glimpses of a future more interesting than we can guess. ☒

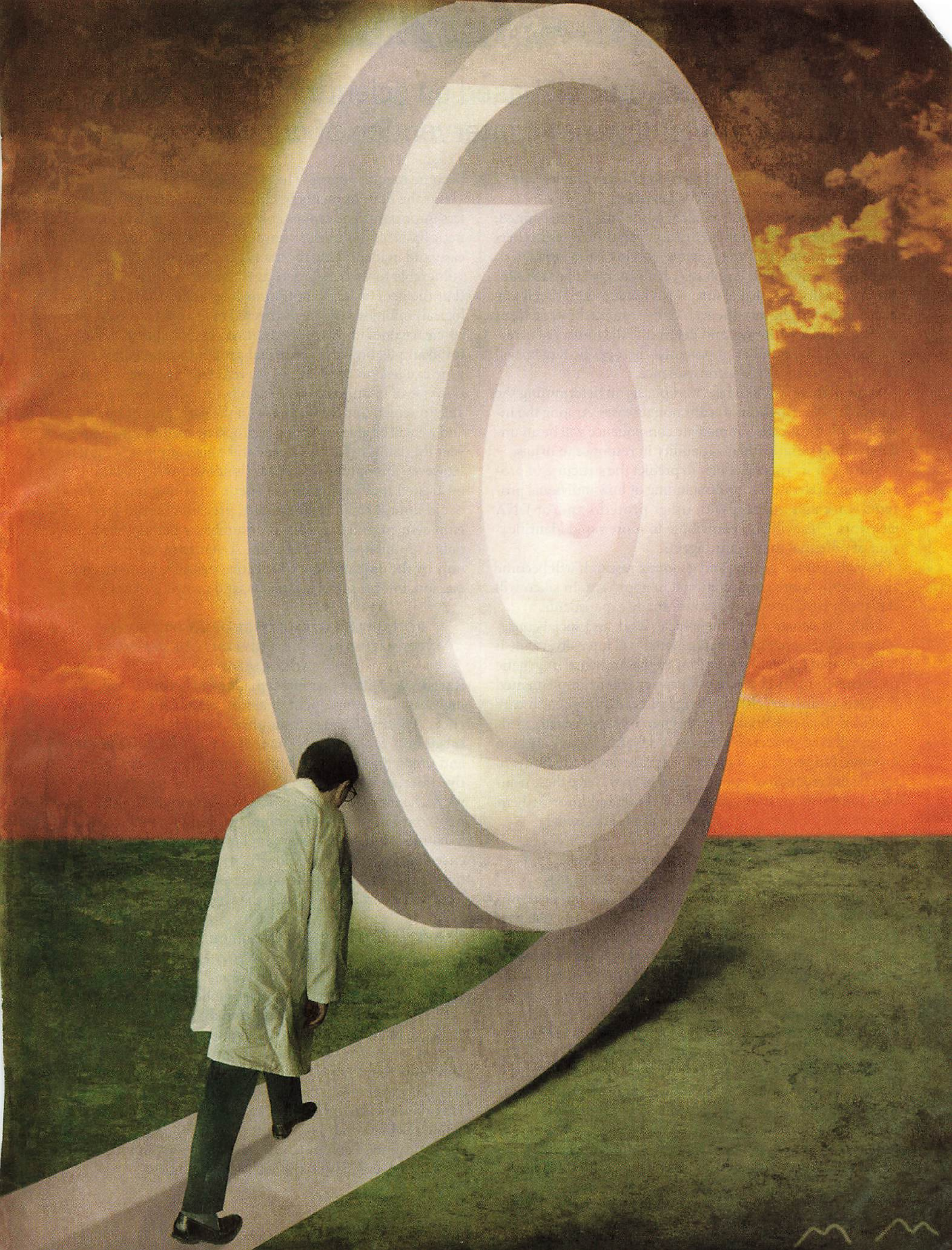
{On the edge of a brave new world.}

Twenty ideas that will rule research in the next twenty years

ILLUSTRATION BY MATT MAHURIN

AS WE HEAD INTO THE 21ST CENTURY, knowledge is being created—and disseminated—far, far faster than ever before. Given this wealth of discovery, we invited some scientists to predict what questions or ethical issues will dominate their fields over the next 20 years. Their replies express not only excitement at the pace of discovery but also a broad concern about the use of new technologies and scientific information. Many noted the impact of the Human Genome Project—and the ethical problems that will attend screening patients' DNA for information about genetic vulnerabilities. Others remarked upon the parallel explosion of information—or, more precisely, surveillance—in cyberspace and how it, too, threatens individual privacy.

The business of science, so to speak, is knowledge. And knowledge is power. Deciding how to handle these new forms of knowledge will be just as important as—and probably far more problematic than—creating the knowledge itself. →



"Furious debates—not all based on scientific facts—will rage about the limits of genetic intervention of our own species"

FRANCIS S. COLLINS, GENETICIST, DIRECTOR OF THE HUMAN GENOME PROJECT

With the sequence of the human genome largely determined, laboratory research of human diseases will shift as researchers adopt a "genome attitude" toward solving problems. First, there will be increased emphasis on a systems approach. Researchers will examine the integrated functions among many genes, gain insight into the web of coordinated interactions among cellular pathways, and determine the impact of external factors. The number of potential therapeutic targets will increase dramatically as a consequence.

Second, there will be a heavy emphasis on determining the hereditary contributions to common diseases. Among the insights with the greatest immediate consequence will be an understanding of individual variability in response to drugs.

Third, our increasing ability to predict the structure of proteins will accelerate our understanding of how individual proteins work and interact with other proteins and/or DNA elements. This will also contribute to more rapid identification of potential therapeutic agents.

Fourth, human genetic and genomic research will become significantly more computational in approach. In silico will replace in vitro or even in vivo for many experiments.

Fifth, the debate about the ethical, legal, and social consequences of research in human genetics will intensify. While it is hoped that legislative solutions to the problems of genetic discrimination and breaches of privacy will be implemented in many countries, the challenge of educating health care providers to be practitioners of this new brand of genetic medicine will be considerable. Furious debates, not all of them grounded in the scientific facts, will rage about the limits of genetic intervention of our own species. To traverse these troubled waters successfully, we will need full and informed engagement by a diverse group of potential stakeholders.

ANTONIO DAMASIO, NEUROSCIENTIST, UNIVERSITY OF IOWA COLLEGE OF MEDICINE

The near future of fundamental neuroscience will be dominated by the problem of consciousness. Curiously, the part of the problem that most thinkers consider difficult, perhaps impossible, to tackle is likely to be elucidated relatively soon. This is the problem of the self, which has to do with how the brain lets us know of our existence as individuals and of the amazing fact that each of us has a private mind that belongs to us and to no one else. But there is another part of the consciousness problem, the part that I describe in my book *The Feeling of What Happens,* as "the movie in the brain." A lot is already known about the molecules, neurons, and circuits with which the brain constructs the sensory patterns necessary to make a movie in the brain. Yet there is a gap in our understanding of how those sensory patterns, which do occur in well-specified circuits of this or that brain region, even become mental images. The challenge is to fill this gap.

But the developments in clinical neuroscience will be no less important. The remarkable success in identifying the genetic basis of single gene disorders, such as Huntington's disease, and in identifying the many genes that make individuals vulnerable to such disorders as Alzheimer's disease, suggests that the genetic contribution to several devastating neurological conditions will be discovered in just a few years. If neuroscience does its job properly, it will be possible to discover, for example, how the abnormal protein produced by a sick gene can lead to the death of nerve cells, thus opening a new universe of treatment possibilities before our eyes. We will be able to screen our own genome in the early part of our lives, and we will be able, by taking appropriate medications, to prevent the damage that a sick gene will cause, or repair it rapidly. However, this optimistic scenario is not without pitfalls. It will be argued that having one's genetic screening made public could limit the choice of a career, preclude certain forms of employment, and make one uninsurable or perhaps insurable only at prohibitive cost. These dire scenarios can be preempted only by the development of effective treatments, much compassion, intense social awareness, and protective laws.

RON GRAHAM, PROFESSOR OF COMPUTER AND INFORMATION SCIENCE, UNIVERSITY OF CALIFORNIA AT SAN DIEGO

It seems very likely that mathematics will become an increasingly essential component of almost all of the emerging sciences. These will range from physics (string theory and the subatomic "zoo"), biology (understanding the human genome and predicting protein folding), computing (creating effective Internet algorithms and guaranteeing security and privacy), chemistry (designing innovative methods for constructing new compounds), and economics (predicting the complex dynamics of the world economy), to name a few. As any science matures, its methods inevitably become more quantitative. So mathematics, as the language of science, is ideally suited for a deeper understanding of the science.

BERNARDO HUBERMAN, THEORETICAL PHYSICIST, XEROX PARC, PALO ALTO, CALIFORNIA

One trend I see having a sizable impact will be our ability to access all kinds of information on a global scale, including genetic and private records of individuals. But we will also create legal and ethical problems around such access. Issues of privacy, ownership, and rights to information will become central to people all over the world, thus leading to the creation of novel mechanisms and international institutions. Twenty years ago, I thought that the most important trends would revolve around nonlinear dynamics and the increased sophistication of computers. But I did not envision the cheap global connectivity that the Internet would bring.

"Our population is exploding—and our ability to take control over our reproduction has not kept pace with the problem"

MARY-CLAIRE KING, PROFESSOR OF MEDICINE AND GENETICS, UNIVERSITY OF WASHINGTON

I think we will explore what it means to be human in new ways. How are we different from our closest relatives? What defines us as a species? What is the genetic basis of our definitive traits? At the genomic level, the answers will be learnable and probably ultimately pretty straightforward. But their philosophical meaning will be immense. Biologists and humanists will need to learn to talk together in ways we have only just begun to develop. I am glad I will still be working on these questions in 20 years.

STEVEN PINKER, PROFESSOR OF COGNITIVE NEUROSCIENCE, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

The biologist E. O. Wilson suggested a useful word for a trend in the human sciences that will accelerate in the next two decades: consilience, the unification of knowledge. The natural sciences will blend into the social sciences and humanities via an understanding of human nature provided by bridging disciplines, such as cognitive neuroscience, evolutionary psychology, and behavioral genetics. This will stand in stark contrast to the two-cultures view in which biology and culture are sealed in parallel universes and it is politically dangerous for one to impinge on the other.

The humanities will be freed from sterile postmodernism and social determinism and be seen as being about products of human minds; they will thereby benefit from insights about perception, cognition, and emotion. Politics and history will be enriched by an understanding of the psychological roots of human aggression, cooperation, coalition formation, and conflict resolution, rather than invoking unanalyzed "social forces." Law will replace its folk theories of free will, deterrence, and "the reasonable person" with ones compatible with neuroscience, genetics, and evolution. Likewise, economics will augment its folk theory of "economic man" with research about human reasoning, decision-making, and passion.

Medicine will transcend its craftsman's understanding of disease and place itself on a theoretical foundation from evolutionary biology. Education will start with a better understanding of which skills develop instinctively in children and which require intensive instruction and hard work.

These changes will not be unopposed. Professional insularity, lazy political arguments, and the ancient doctrine that the mind is a blank slate will slow them down. But the gains in insight will be too great to halt them for long.

LEE SMOLIN, PROFESSOR OF PHYSICS, PENNSYLVANIA STATE UNIVERSITY

During the next 20 years a revolution in physics that has been in progress since Einstein overthrew Newtonian physics will culminate in a new physical theory. It will combine all we have learned in the last century about relativity, quantum theory, elementary particle physics, and cosmology. The remainder of the time will be spent working out its implications. Dramatic progress in observational cosmology and experimental physics will also give rise to tests of the new theory. Then physicists and cosmologists will be able to attack questions on which progress was not previously possible, such as what happened before the Big Bang and why the universe is hospitable to life.

The next 20 years also will be remembered as the time that real progress began to be made resolving the great problems of origins: the origin of life, the origin of galaxies, the origin of the human species, the origin of language and human social organization.

On the ethical side, the rapid growth of new opportunities outside the universities for people with scientific training will sooner or later give rise to a long overdue reform of the university system. Universities are among the most bureaucratic institutions in society; they will have to reform to compete for talent. The important ethical question is the extent to which these reforms can be managed to foster the main values of the university: teaching, research, and scholarship. The question will be how to protect and foster these necessarily labor-intensive and fragile activities within new organizational structures that will resemble much more the horizontal structures of small technical companies than they do the present rigid and hierarchical university system.

CHRISTOPHER WILLS, PROFESSOR OF BIOLOGY, UNIVERSITY OF CALIFORNIA AT SAN DIEGO

Twenty years ago the Human Genome Project was not even a gleam in anybody's eye. Today the project is virtually complete. Much has been written about the project's impact on understanding cancer and aging and on the possibility of finding genes for intelligence and behavior. But another aspect of the project may be the most important of all. Our population is exploding, leading to widespread environmental damage, wars over shrinking resources, and famines. Our ability to take control over our reproduction has not kept pace with the problem. Condoms, the most widely used device for preventing conception, were employed by the ancient Egyptians in 1000 B.C. The Pill is a crude manipulation of female hormone levels that can have undesirable side effects.

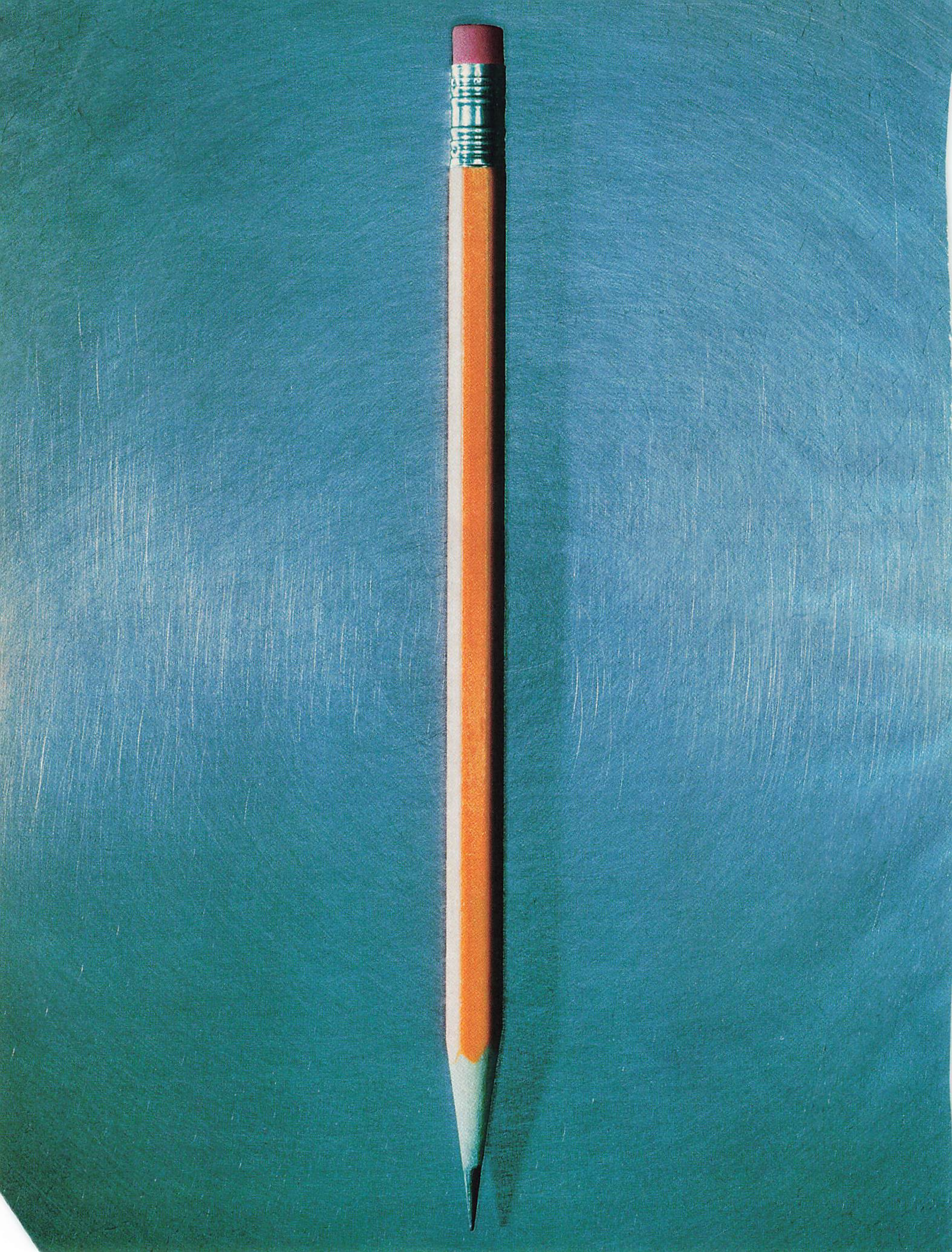
Now, thanks to the Human Genome Project, we have the sequences of all the genes involved in human reproduction. This includes all the genes involved in the production of sperm, all the genes that govern the environment inside the uterus, all the genes involved in ovulation and implantation, and all the genes that code for neuropeptides and other hormones that influence sexual behavior. We do not yet know how most of these genes work, but the opportunities for finding cheap, safe, effective, and reversible ways to prevent conception are boundless. Let's find them before the next 20 years are up.

{There will still be a Super Bowl.}

Twenty things that won't change in the next twenty years

BY BRAD LEMLEY

PHOTOGRAPHS BY DAN WINTERS



IN *THE DOOR INTO SUMMER*, A CLASSIC SCIENCE-fiction novel published in 1957, author Robert Heinlein predicted that by the year 2000 we'd all enjoy robot butlers, cryogenic sleep, and antigravity transport, as well as the conquest of all forms of disease.

You bet, Bobby.

One can hardly blame Heinlein for purpling the future. After all, it would be tough to write a gripping novel about slightly fancier cars, color TV, and digital watches. But the real world never changes as quickly as the fevered imaginations of writers, futurists, and other visionaries tell us it will. Progress is, and probably always will be, an incremental business.

Looking 20 years into the future, the likelihood is that our daily home, work, and recreational pursuits will look a great deal like they do now—just as life today isn't terribly different from what it was in 1980. And is that so bad?

Here are 20 facets of everyday life that we can count on remaining fundamentally the same right up until Super Bowl LIV:

Houses. From 1957 to 1967, millions of visitors trooped through a plastic UFO-shaped abode at Disneyland called the Monsanto House of the Future. No more were ever built. Since the historic-renovation revival of the 1960s, Americans have settled on circa-1880 architecture as the apotheosis of residential aesthetics. Both the brand-new Victorians dotting the coast of Nantucket island and the cinder block faux-adobe houses in Santa Fe would be instantly familiar to Chester A. Arthur or Buffalo Bill Cody. And because people grow attached to the house styles they grew up with, tastes are unlikely to radically change anytime soon. In any case, the houses of 2020 are, for the most part, already built. Of the 110 million housing units in the United States today, roughly 70 percent will still be around two decades from now, according to Department of Housing and Urban Development figures.

Pencils. Beginning in 1565, when Swiss physician Conrad Gesner of Zurich first described a pencil as a writing rod held in a wooden case, the pencil underwent a slow development—eraser on the end, paint to forestall splinters, flat sides to retard rolling—that hit a plateau more than a century ago. Today's pencil is a classic example of evolved engineering, says Henry Petroski, a Duke University engineering professor and author of *The Pencil: A History of Design and Circumstance.* Pencil sales, he notes, have remained steady right through the word-processing revolution, because the old advantages remain: "It can be erased, sharpened with a penknife, requires no batteries, needs no ink supply, and is cheap." He expects the pencil's shape and sales to remain relatively fixed through 2020.

Books. Nicholas Negroponte, director of MIT's Media Lab, has predicted that books will soon evolve into bound volumes of paperlike, rewritable leaves. Some books may go this route—labs worldwide are laboring on paper-mimicking interfaces—but traditional books have 500 years of inertia behind them, and no wonder. They are stable, cheap, durable, lightweight, and a hassle to pirate, virtues that e-books of any kind will be hard-pressed to emulate in a mere 20 years.

Cash. Despite frequent predictions that microchip-bearing "smart" cards will soon replace cash, hard currency remains popular, and will remain so. A report issued in October 1999 by Retail Banking Research in Great Britain proclaims, "Cash use is set to continue at similar levels to the present for at least several more decades." Cash appeals to banks, who profit from ATM dispensing fees. It also changes hands easily, tucks neatly into garter belts, and crosses borders without leaving any traces. Money talks, but in the form of cash, it can also keep quiet, and that's an appeal that's unlikely to wane.

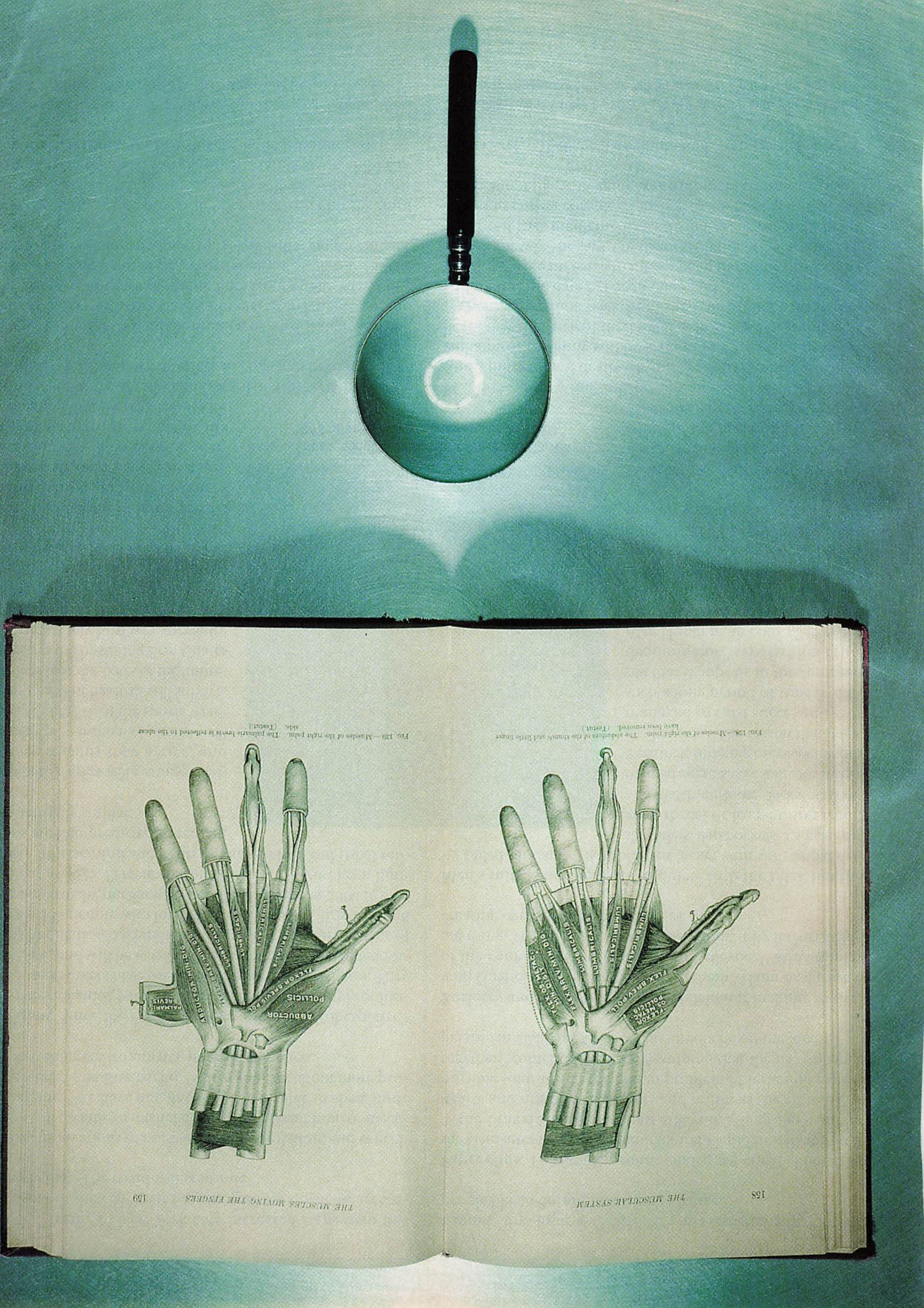
Eating utensils. In 1611, Thomas Coryat, an Englishman, brought forks from Italy to Britain, promoted their use, and was ridiculed and considered effeminate for his efforts. But today, the fork and its prehistoric mates, the knife and spoon, constitute a culturally validated food-dispatching triumvirate, according to Petroski, in his book *The Evolution of Useful Things.* In the Western world, at least, these three basics are likely to attack whatever tofu permutation we're munching two decades from now. And in the East, Petroski predicts, chopsticks will continue to serve as they have for millennia.

Passenger jets. Concept drawings of supersonic, stratospheric aircraft are intoxicating. NASA's High Speed Civil Transport, capable of zooming 300 passengers at 1,500 miles per hour, could go into mass production in 15 years. But the average life span of a contemporary passenger jet is more than 20 years, notes George Bugliarello, editor of the journal *Technology in Society.* So the noisy, cramped, and relatively poky jets aloft at this moment will more than likely still be in service in 2020. Anyway, most of the advancement in new aircraft construction over the next two decades, predicts Bugliarello, will be in size, not speed. Huge planes on the drawing boards at Airbus and Boeing may save money for airlines but do little or nothing to improve the flying experience of passengers.

Driving. In an August 1997 demonstration, eight cars carried hands-off "drivers" down a seven-mile stretch of the San Diego Freeway. Self-driving cars have obvious advantages: They allow closer spacing and faster speeds and minimize the danger of human error. But widespread implementation, even by 2020, remains far from probable. Autopilot systems for trains and airplanes fail frequently, requiring trained humans to step in and (usually) avert disaster. If automated car guidance goes awry, it's unlikely garden-variety drivers will be just as vigilant. After all, if they wanted to carefully monitor the system, why would they buy an autopilot car? Result: Liability concerns will make automakers skittish for the foreseeable future. Minor flourishes, such as range-finding cruise control that prevents tailgating, will be adopted long before autopilots.

Traffic congestion. Flying cars won't get us out of a jam either. "Cars will still roll along on the ground, and congestion will be a fact of life," predicts Bugliarello. In fact, it will get

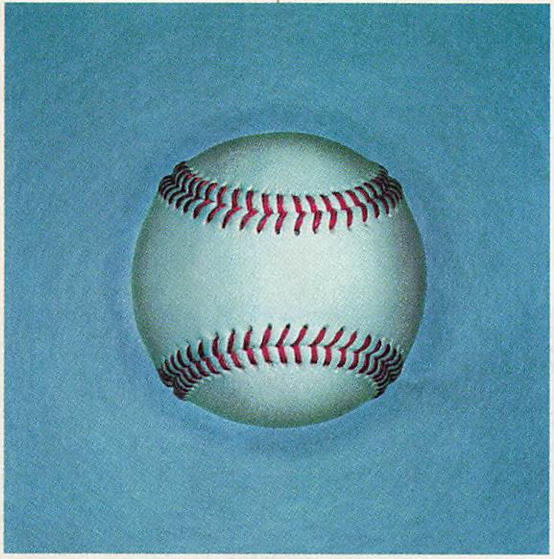
The visual resolution of a typical book—1,440,000 dots per square inch—is up to 277 times sharper than that of an average computer screen.


158 THE MUSCULAR SYSTEM
FIG. 138.—Muscles of the right palm. The abductors of the thumb and little finger have been removed. (Testut.)
THE MUSCLES MOVING THE FINGERS 159
FIG. 139.—Muscles of the right palm. The palmaris brevis is reflected to the ulnar side. (Testut.)
ABDUCTOR POLLICIS
FLEXOR BREVIS POL.
PALMARIS BREVIS
LUMBRICALES
FLEX. BREVIS POL.
LUMBRICALES

worse. "Traffic in New York City increased 30 percent this decade, but the city itself has changed very little to accommodate that. The trend will continue."

Noise. Innovations in noise isolation, insulation, and cancellation will do little to ratchet down the incessant hum of mechanized life. "We have not, and will not, be able to abate noise very much," says Bugliarello. "When you talk about more people in tighter environments, noise will be there."

Religion. Since the French Revolution, when Robespierre's followers renamed Notre-Dame Cathedral the "Temple of Reason," freethinkers have predicted the demise of religion. They were, are, and will be wrong. Projections based on United Nations population data indicate that in 2025, the percentage of the world's people who identify themselves as Christians will remain virtually unchanged, from 33.4 percent in 2000 to 35.5 percent in 2025. Percentages of Muslims, Hindus, Jews, Buddhists, atheists, and adherents of various folk and tribal religions are also predicted to remain substantially similar.



Baseball rules, codified by surveyor Alexander Cartwright in 1845, aren't likely to change much by 2020.

Baseball. Players will get bigger, 80-homer seasons may arrive, and something—women's soccer?—will eat a larger slice of the sports viewership pie. But baseball will survive, predicts Joseph Coates of the future-megatrends consulting firm Coates & Jarratt. Only how we experience it will change. "Every little factory in the South used to have its own team," says Coates. "That kind of participation won't return."

Sex. The advent of cloning, genetic manipulation, and extraordinary advances in joining eggs and sperm in test tubes will no doubt be embraced by a growing part of the population. But the real deal—with its ancient freight of risks and rewards—will certainly be the dominant reproductive interface in 2020 and beyond.

Zippers. By 2000, Heinlein predicted, we'd fasten clothing with polarity-reversing clasps. But electromagnetics are too unreliable for the task of hiding flesh from public view. Only an interlocking chain of clasps, preferably of steel, will do. The zipper, in development since 1851, will suffer no pretenders.

Poverty. A rising tide of world prosperity won't lift the third world's boats, at least not by 2020. We will still witness "mass starvation in the third world," predict Ian Pearson and Peter Cochrane, futurists for British Telephone Laboratories.

Shopping. Despite the inevitable e-commerce onslaught, "Real stores that people can walk through will definitely still be around," says futurist Coates. "It's just something that lots of people like to do, and that won't change."

Paper clips. The familiar round-ended paper clip, known as the Gem after its British manufacturer Gem Limited and sold in the United States for at least 100 years, "long ago won the hearts and minds of designers and critics as the epitome of possible solutions to the design problem of fastening papers together," contends Petroski. Assuming that the use of paper persists in 2020, the Gem will assuredly be on the job.

Zealotry and terrorism. "We will retain our inability to deal with fanaticisms of all kinds," predicts Sesh Velamoor, a trustee of the Foundation for the Future in Bellevue, Washington. If anything, Velamoor sees the havoc wrought by terrorists increasing over the next two decades.

Men's suits. Skirt hemlines undulate with the tides, but the so-called sack suit—a nondarted jacket with soft, unpadded shoulders, flap pockets, a single rear vent, three- or four-button front, and matching, loose slacks—has remained aggressively static for nearly a century, suffering only lapel-width oscillations. "The reason that it has managed to exist successfully for such a long period of time is simply that it appeals to the common denominator," says fashion critic Alan Flusser in his book *Clothes and the Man.* In other words, a sack suit offers an attractive mix of status, conformity, and anonymity. Dress-down Fridays and Silicon Valley polo-khaki chic notwithstanding, the suit will survive.

Death. "We will never conquer death," predicts Dr. Michael Fossel, editor of the *Journal of Anti-Aging Medicine.* For starters, getting hit by a bus—even a fuel-cell-powered one—will still be fatal. And a more typical death—from, say, deteriorating organs—will almost certainly still be around in 2020. But Fossel believes that the ancient threat will at least have begun to ebb. "When people look back from the year 2100, I believe they will pick some date between 2005 and 2015 as the point at which we were first able to intervene in the aging process in a significant way," he says. On the other hand, some researchers point out that medicine has a dismal track record when it comes to curing complex, chronic diseases such as diabetes and hemophilia. And aging is the ultimate chronic disease.

Dick Clark. At 90, he'll no doubt look younger than ever. ☒

Conformists won't vanish by 2020; nor will the sack suit, which fashion critic Alan Flusser describes as "so anonymous, it offends no one."

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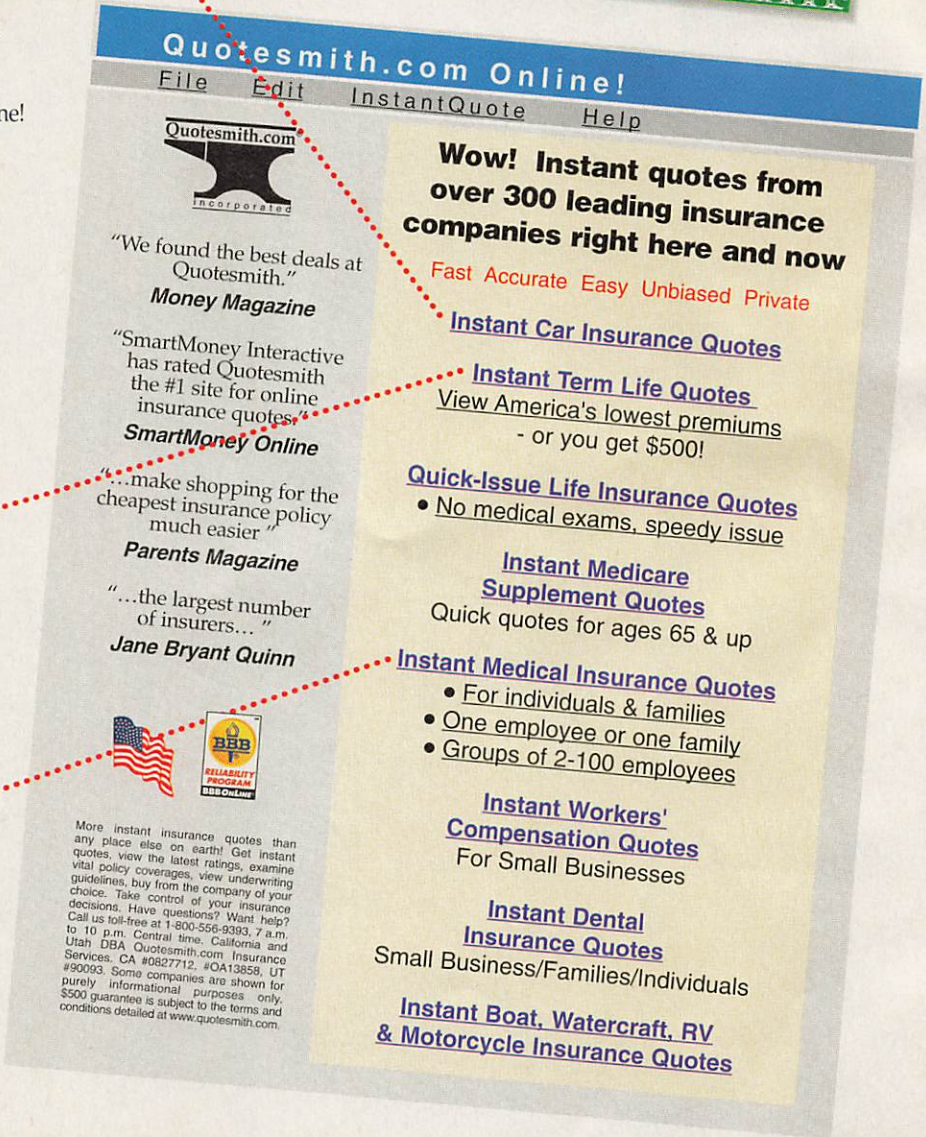

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CALIFORNIA SCIENCE CENTER

Museum goers get a chance to lose their heads at the California Science Center in Los Angeles. The nifty optical illusion relies on the precise placement of a single mirror.

museums

It's No Illusion

Magicians and scientists are siblings under the skin

BY THOMAS FIELDS-MEYER

MORE THAN 4,000 YEARS AGO, AN EGYPTian named Dedi walked into the court of King Cheops and entertained the monarch and his subjects by decapitating oxen and geese and then reaffixing their heads, restoring the sorry creatures to vibrant life. How did he do it? Dedi didn't reveal his secret, but anthropologist Diane Perlov is sure she knows. "All magic is based on scientific principles," she says. "Yet most people don't connect science with magic." The connection goes even deeper: Both performing artist and practicing scientist are motivated by a sense of wonder at the world's essential mystery. "Magicians capture that wonder, while scientists try to explain it," Perlov says. "But neither loses the appreciation that got them started in the first place."

That shared fascination is on view in Magic: The Science of Illusion, an engaging new exhibit at the California Science Center in Los Angeles. Perlov, the show's curator, has assembled films and artifacts of famed performers, including the handcuffs and milk can Houdini used in his dazzling escapes. Even better, Perlov has enlisted the help of some of today's master magicians to create unique illusions visitors can then duplicate.

In one of the most intriguing, the Amazing Living Head by the offbeat comic duo Penn & Teller, Penn recounts how Teller has suffered a horrific car crash that has left his head separated from his body. A video monitor displays Teller's live disembodied head on a futuristic-looking stainless steel platform. Next to the screen is a small stage set visitors can enter to create the illusion that they, too, have lost their heads. Teller (always silent on stage) later explains that the trick is based on the simple optical principle that the angle of incidence is equal to the angle of reflection. That is, light bounces off a mirror at the same angle at which it arrives. "If you understand that," he says, "it's not hard to create illusions like these."

Science fiction writer Arthur C. Clarke once opined that "any sufficiently advanced technology is indistinguishable from magic." Indeed, for centuries magicians have employed the latest technology in their art. In the Light and Heavy Chest, modern magician Jade first performs on tape an illusion invented by Jean-Eugène Robert-Houdin, the 19th-century Frenchman who is considered the father of modern conjuring. Then Jade's recorded voice asks a museum visitor to lift a chest and set it down. No problem. Moments later, after following instructions to lean on two targets, the same person tries again and fails. The explanation: The visitor has unknowingly switched on a powerful hidden electromagnet that locks onto a metal plate in the lining of the chest.

In the 1850s, Robert-Houdin easily astounded a public that wasn't well informed about new technology like the electromagnet. That isn't the case today. "When you can sit on an airplane and somebody next to you is demonstrating the latest gadget," says Teller, "it's very hard to amaze people on the technological front."

Some performers, of course, don't depend on devices at all. In the Magic of Mind, Max Maven divines which of several shapes a person is thinking of—a crescent? A triangle? The mentalist's secret: mathematics. When Maven asks the volunteer a series of questions, he's using a binary sorting program, in the way a computer uses mathematical patterns to run a search program. That doesn't explain, though, how in a live performance Maven can correctly guess that an audience volunteer has spent time at a remote village in Fiji. "One of the values of magic to science and society," says Maven, "is to remind us we're surrounded by mysteries."

And that might be the best trick of all.

Magic: The Science of Illusion will be at the California Science Center through February. It travels to Philadelphia April 1 and Fort Worth next October; the exhibit will tour the United States through 2007. For information, call 323-SCIENCE or surf to www.casciencectr.org.

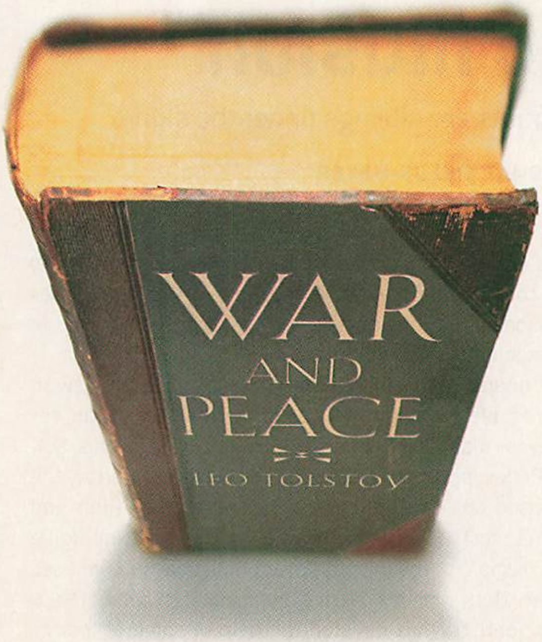
television

BUILDING BIG

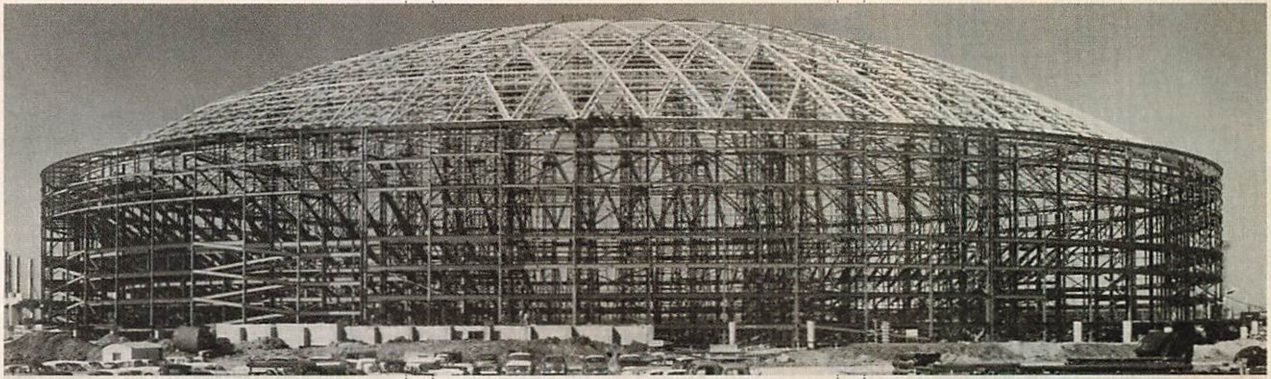
A PBS miniseries produced by WGBH Science Unit, Boston, and Production Group Inc. of Washington, D.C.
First episode airs October 3; check your local listings for times.

EVERY DAY, MILLIONS OF TRAVELERS CROSS bridges like the Golden Gate, the Brooklyn, and the 2,050-year-old Ponte Fabricio in Rome without giving much thought to what holds them up. Other millions blithely traverse tunnels, live below dams, sit under stone domes, and ascend skyscrapers in perfect trust. But it wasn't always so, as this five-part series illustrates.

Indeed, much safety now rests on foundations created from the rubble of failures, explains David Macaulay, series host and author of the companion book *Building Big* (Houghton Mifflin, $30). For example, attempts to tunnel under the Thames River met with crushing defeat until 1824, when French engineer Marc



THE NIGHTTIME, SNIFFLING, SNEEZING, COUGHING, ACHING,



An intricate web of steel trusses supports the Houston Astrodome.

Brunel took inspiration from a helmet-headed worm that bores into ships. He decided to try a similar shield to hold dirt walls in place as workers dug their way forward. Brunel's tunnel collapsed twice before he got it right, but it survives to this day as part of the London Underground, and the concept is incorporated into modern tunnel-boring machines. Similarly, the 1879 collapse of a post-and-beam railroad bridge in Scotland led engineers John Fowler and Benjamin Baker to rethink lengthy spans in windy areas. They came up with the cantilever bridge, in which towers anchor a series of trusses that extend out like diving boards to suspend a railway or road. To show nervous spectators the design could be trusted, Baker perched on a narrow board supported by two assistants acting as towers.

As disparate as dams and domes and the other gigantic structures may seem, many share a basic construction element: the arch. To demonstrate its effectiveness, Macaulay uses an animated cartoon of an elephant jumping up and down on a simple arc of stones. Soon the rocks pop out sideways. But when the arc is covered with layers of stones, the added weight compresses the structure, making it stable and impervious to even the most determined pachyderm. That principle is hardly new. Ancient Romans built bridges, aqueducts, and domes using the idea, Gustave Eiffel applied the concept when he built his famous tower, and Hoover Dam is really just

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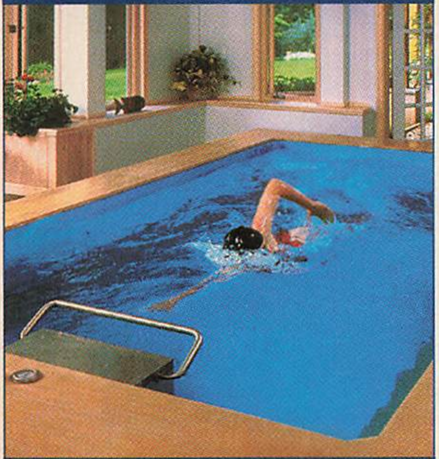

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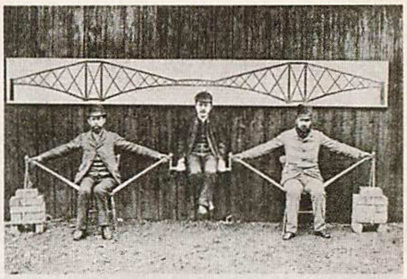


In 1890, British engineer Benjamin Baker (center) demonstrated how a cantilever bridge design works.

a sideways arch that uses water as the compressive force. But without a clever series like *Building Big*, one might never notice the marvels of engineering in everyday life, and knowing those principles makes crossing a bridge a much more engaging experience. —*Fenella Saunders*

VALLEY OF THE GOLDEN MUMMIES
Zahi Hawass
Abrams, $49.50.

CONVERSATIONS WITH MUMMIES: NEW LIGHT ON THE LIVES OF ANCIENT EGYPTIANS
Rosalie David and Rick Archbold
William Morrow, $40.

EVERY MONTH BRINGS BEAUTIFUL NEW books on ancient Egypt, but these two are exceptional finds. Particularly welcome is Zahi Hawass's lyrical account of excavations in the Valley of the Golden Mummies. So much of what we know about the lives of early Egyptians has been filtered through Western scientists. Hawass provides not only the perspective of an archaeologist—he is director general of the Giza Pyramids and field director of the Bahariya Oasis excavation—but also that of a native steeped in the land and the culture. His evocative narrative weaves together stories of the upper-middle-class families buried in the Valley with tales of modern Egyptians who dwell in the villages nearby.

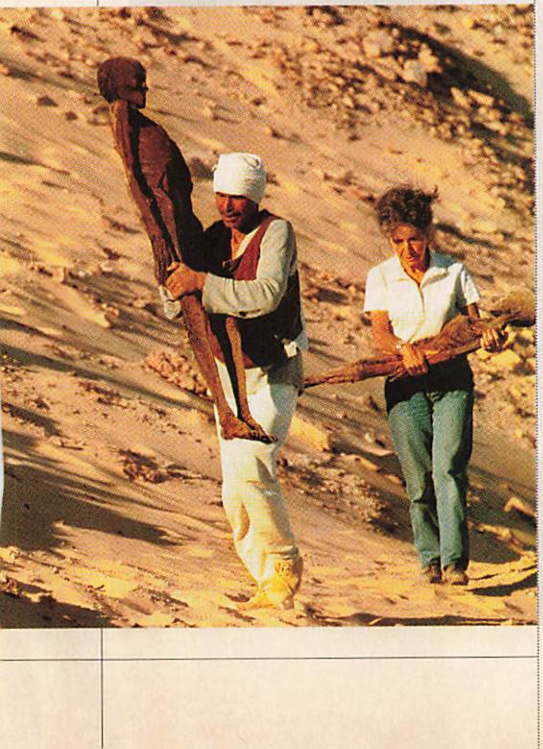
Equally compelling is Hawass's recall of everyday life at a dig, its sights, sounds, and smells (a newly unearthed mummy gives off an overwhelming stench). In a story worthy of a late-night movie, Hawass tells of being woken from sleep by images of two children. He recognized the faces

THE INSTITUTION OF CIVIL ENGINEERS; OPPOSITE: STEPHANE COMPOINT/SYGMA

as belonging to the boy and girl mummies that had been removed to a nearby museum. After weeks of sweat-drenched awakenings, he concluded that the children could not rest because they had been separated from their father. As soon as Hawass placed the father's mummy beside the children's, the hauntings ceased.

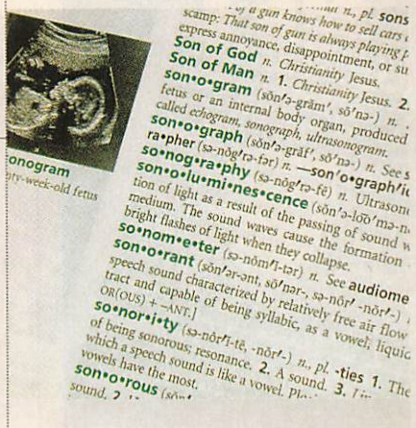
Less mystical but just as absorbing is Rosalie David's book. The director of the Egyptian Mummy Research Project at England's Manchester Museum offers fascinating history (mummy unwrappings were a frequent highlight of country weekends among the Victorians) and observations (every mummy has a unique scent) that museum visitors are not likely to come across on their own. But she is most interested in what can be learned about ancient Egyptians' health, habits, and living conditions from their physical remains. With science writer Rick Archbold, she details how researchers use the tools of modern science, from CAT scans to DNA analysis, to extract answers from their silent subjects. The process is so intimate, says David, that "after a while one begins to feel as though one knows each of them personally." *—Rabiya S. Tuma*

Mummies of ancient Egyptian farmers are carried away for study before being returned to their tomb in a sandstone cliff.



THE AMERICAN HERITAGE DICTIONARY OF THE ENGLISH LANGUAGE, FOURTH EDITION
Houghton Mifflin, $60.

IF YOU'RE STILL DOUBTING THE PACE OF technological change and scientific discovery, check out the latest edition of this workhorse dictionary. Of 10,000 words added since the last revision eight years ago, nearly a third relate to the sciences. Thumbing through the tome's 2,074 pages, you'll find new entries in virtually every



onogram
ty-week-old fetus

scamp: That son of gun knows how to sell cars
express annoyance, disappointment, or su
Son of God *n. Christianity* Jesus.
Son of Man *n.* **1.** *Christianity* Jesus. **2.**
son•o•gram (sŏn′ə-grăm′, sō′nə-) *n.*
fetus or an internal body organ, produced
called *echogram, sonograph, ultrasonogram.*
son•o•graph (sŏn′ə-grăf′, sō′nə-) *n.* See s
ra•pher (sə-nŏg′rə-fər) *n.* **—son′o•graph′i**
so•nog•ra•phy (sə-nŏg′rə-fē) *n.* Ultrason
son•o•lu•mi•nes•cence (sŏn′ə-lo͞o′mə-n
tion of light as a result of the passing of sound w
medium. The sound waves cause the formation
bright flashes of light when they collapse.
so•nom•e•ter (sə-nŏm′ĭ-tər) *n.* See **audiome**
son•o•rant (sŏn′ər-ənt, sō′nər-, sə-nôr′-nōr′-)
speech sound characterized by relatively free air flow
tract and capable of being syllabic, as a vowel, liquid
OR(OUS) + -ANT.]
so•nor•i•ty (sə-nôr′ĭ-tē, -nŏr′-) *n., pl.* **-ties** **1.** The
of being sonorous; resonance. **2.** A sound. **3.**
which a speech sound is like a vowel.
vowels have the most.
son•o•rous
sound.

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Aage Kristiansen
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field, from archaeology to zoology. Some of the new listings are bound to be familiar, like *Viagra* and *greenhouse gas*. Others are sure to startle. Try *sonoluminescence* and *seaborgium*, for starters. And did you know that *rutherfordium*, an artificially produced radioactive element, is also called *unnilquadium*? This dictionary even offers the lowdown on its isotopes and half-lives. Such a rich trove of new learning is sure to occupy you for many, many *yoctoseconds*. *—Eric Powell*

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FREE FOR ALL: HOW LINUX AND THE FREE SOFTWARE MOVEMENT UNDERCUT THE HIGH-TECH TITANS

Peter Wayner

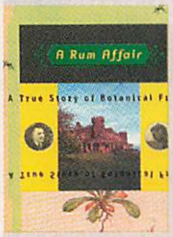
HarperCollins, $26.

To techie adherents of the open-source movement, free software is a way of life. For the rest of us, Wayner, a computer scientist and journalist, has charted the history of hackers who devote their spare time to writing code they make available to anyone free of charge. Their efforts, he insists, will soon change computing forever.

A RUM AFFAIR: A TRUE STORY OF BOTANICAL FRAUD

Karl Sabbagh

Farrar, Straus and Giroux, $24.



In the 1940s, respected professor John Heslop Harrison astonished British botanists with his discovery of nonnative grasses on Scotland's Isle of Rum. John Raven, a young Cambridge don, challenged the findings and eventually proved that Harrison had smuggled the grasses onto the island. A poignant and sometimes comic tale of out-of-control ambition.

$E=MC^2$: A BIOGRAPHY OF THE WORLD'S MOST FAMOUS EQUATION

David Bodanis

Walker & Company, $24.

"The equation that changed everything" is familiar to even the most physics-challenged, but it remains a fuzzy abstraction to most. Science writer Bodanis makes it a lot more clear. He straightforwardly explains the meanings of $\mathcal{E}$, m, and c^2, then leads us through the steps Einstein took in arriving at his formulation, and finally chronicles where the equation has taken the world.

THE TWO-HEADED BOY AND OTHER MEDICAL MARVELS

Jan Bondeson

Cornell University Press, $29.95.

Jan Bondeson
THE TWO-HEADED BOY
and Other Medical Marvels

English physician Bondeson uses centuries-old medical records, engravings, and paintings to sensitively document the lives of some of nature's strangest creations, among them hog-faced women, dog-faced boys, and horned humans.

LAUGHTER: A SCIENTIFIC INVESTIGATION

Robert R. Provine

Viking Publishing, $24.95.

Why do we laugh? Neurobiologist Provine provides some answers but cautions that there will probably never be a Grand Unified Theory of Laughter. A highly entertaining—if not laugh-out-loud funny—read.

LEONARDO DA VINCI

Sherwin B. Nuland

Viking Penguin, $19.95.

LEONARDO: THE FIRST SCIENTIST

Michael White

St. Martin's Press, $27.95.

Two new books argue that Leonardo da Vinci, the quintessential Renaissance man, was a scientist first and an artist second. Nuland, a gifted essayist and surgeon, explores Leonardo's remarkable career as an anatomist. Journalist and scientific historian White links the details of the genius's life to his extraordinary career as an inventor. Both books benefit from reproductions of Leonardo's rich anatomic illustrations, which testify that he wasn't such a bad artist either.

RUBE GOLDBERG: INVENTIONS!
Maynard Frank Wolfe
Simon & Schuster, $25.
In the first half of the 20th century, newspaper cartoonist Goldberg's fantastic inventions were often more famous than most actual innovations. This compilation of more than 100 of Goldberg's most hilarious and sly cartoons will appeal to the secret Luddite in everyone.

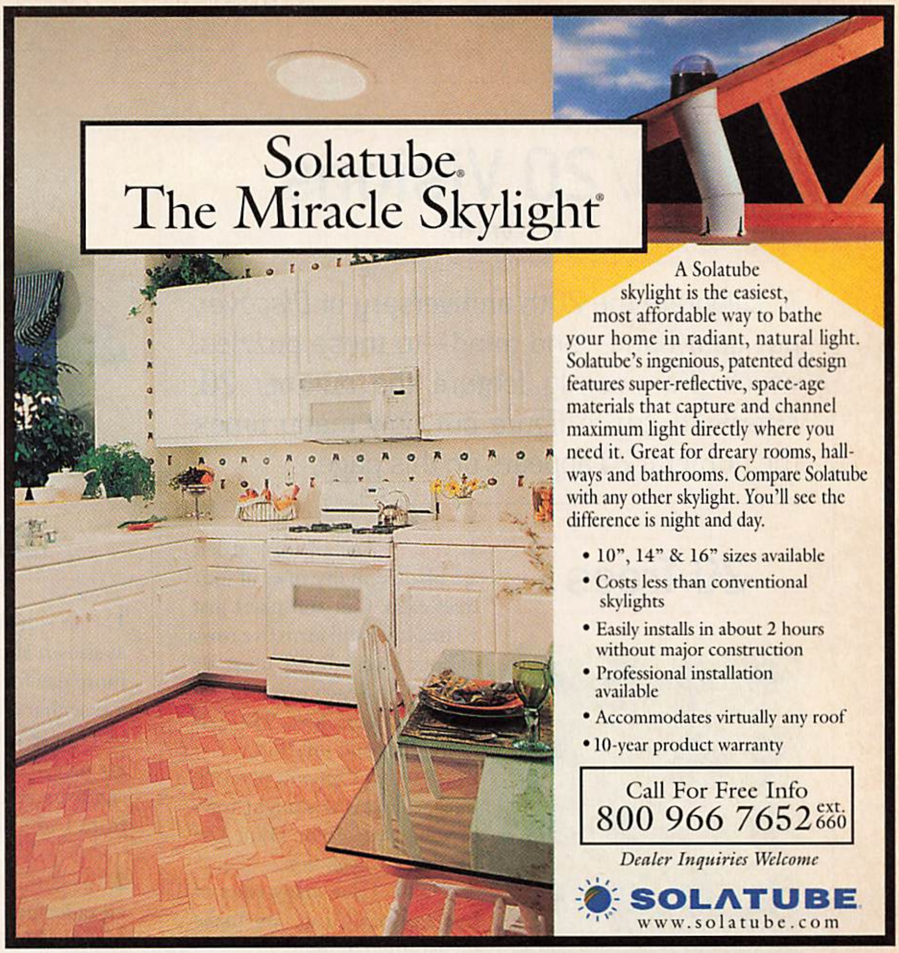
STARDUST: SUPERNOVAE AND LIFE—THE COSMIC CONNECTION
John Gribbin with Mary Gribbin
Yale University Press, $24.95.
Current theory holds that all of Earth's matter, except for hydrogen, was formed in the crucibles of supernovas. Astrophysicist John Gribbin and science writer Mary Gribbin use elegant and precise language to explain that we are literally made of the same stuff as stars.

BLAZE: THE FORENSICS OF FIRE
Nicholas Faith
St. Martin's Press, $23.95.
Journalist Faith revisits some of the past century's most catastrophic blazes, including those at the Triangle Shirtwaist Factory in New York and the MGM Grand Hotel in Las Vegas, to give a gritty account of how investigators use everything from old-fashioned detective work to computer modeling to zero in on the causes of fire.

BLAZE
THE FORENSICS OF FIRE
NICHOLAS FAITH

EXPLORING NATIVE NORTH AMERICA
David Hurst Thomas
Oxford University Press, $39.95.
Using photographs, maps, and site plans, archaeologist Thomas gracefully reconstructs the scientific and technological achievements as well as the art, religion, and trade of early Native American inhabitants of 18 sites across the United States and Canada.

—compiled by Eric Powell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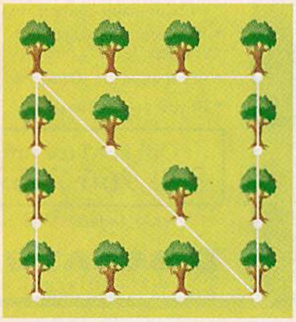
Quote: Frank Beacham, *Radio World*, 12/93. Reprinted with permission.

20/20 Visions

BY SCOTT KIM

To celebrate the 20th anniversary of *Discover,* put your hand—and mind—to these puzzles, which prominently feature the number 20. Afterward, try to figure out how many times the numeral 20 appears on this page.

20 Trees



1. **{EASY}** The 14 trees at left are planted in five rows of four trees each. Can you plant just 10 trees and still form five rows of four trees? Rows must be straight, and each row must lie on a different line. There is more than one solution.
2. **{MEDIUM}** Can you plant 20 trees to form 20 straight rows of four trees each? Hint: Use the previous solution.
3. **{HARD}** How many rows of five trees each can you make by planting 20 trees?

20 Questions

1. **{EASY}** Someone is thinking of a whole number between 1 and 1,000,000. How can you find out this number by asking 20 yes-no questions?

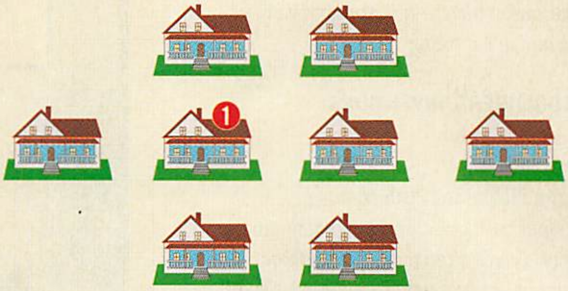
2. **{MEDIUM}** Again, someone is thinking of a whole number between 1 and 1,000,000. You can ask questions to which the answer is always one of three choices: a, b, or c. How many questions must you ask to be certain what number he has in mind?

3. **{HARD}** Now someone is thinking of a whole number between 1 and 100. Suppose you ask the following 20 yes-no questions:

Is the number evenly divisible by 1?
Is the number evenly divisible by 2?
Is the number evenly divisible by 3?
And so on, up to: Is the number evenly divisible by 20?

Based on the answers, you may or may not be able to figure out the number. For instance, you can't distinguish the numbers 16 and 32 from the answers to these yes-no questions, since both numbers are divisible only by 1, 2, 4, 8, and 16. What numbers are indistinguishable from 27? From 20? 4? 97? 93?

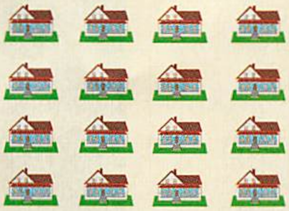
4. **{FORGET ABOUT IT}** List all the numbers between 1 and 100 that you can deduce with certainty from the answers to the 20 questions described in Problem 3.



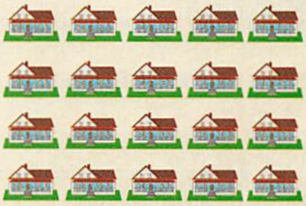
20 Painted Houses

1. **{EASY}** The city of Octopolis has eight houses arranged as shown above. It takes one day to paint a house and one more day for the paint to dry. Local laws forbid painting a house that is adjacent horizontally, vertically, or diagonally to a house whose paint is still wet, because the paint fumes are too strong. Can you figure out an order in which you can paint all eight houses in eight days? Number the houses from 1 to 8 in the order in which you would paint them.

2. **{MEDIUM}** The teeming and rigidly structured city of Hexadecipolis comprises 16 houses arranged in four rows of four. A house can be painted in one day, but it takes two days for the paint to dry. Again, local laws forbid painting a house that is adjacent to a house with wet paint. Can you determine an order that lets you paint all 16 houses in 16 days? Hint: The numbering on adjacent houses must differ by at least 3.



3. **{HARD}** Hexadecipolis's sister city, Icosapolis, known as the Humid City, has 20 houses arranged in four rows of five. Houses can still be painted in one day, but now it takes three days for the paint to dry. And, of course, you can't paint a house adjacent to one that is still wet. Is there an order in which you can paint all of the houses in 20 days? Hint: The numbering on adjacent houses must differ by at least 4.



4. **{TRULY BOGGLING}** An intense summer has descended upon Icosapolis, and it now takes four days for paint to dry. It's not the heat; it's the humidity. Can you figure out how to paint all 20 houses in 21 days?

FOR BOGGLERS SOLUTIONS, TURN TO PAGE 108. FOR MORE BOGGLERS PUZZLES, GO TO WWW.DISCOVER.COM.

ILLUSTRATIONS BY ERIC CLARO

re sources

Consult these sources to learn more about topics featured in *Discover* this month.

8 CONTRIBUTORS
For more of McCall's work, from the James Goodman Gallery, see www.jamesgoodmangallery.com/mccall/pages/exhibframez.html.

17 R&D
"Odor Engineers." "Developmental Regulation of Methyl Benzoate Biosynthesis and Emission in Snapdragon Flowers," Natalia Dudareva et al., *The Plant Cell,* Vol. 12, pp. 949-961, June 2000 or www.plantcell.org.

"The Emperor's New Genome?" "Will Genetics Revolutionize Medicine?" Neil Holtzman and Theresa Marteau, *The New England Journal of Medicine,* July 13, 2000, pp. 141-144. For more about the Human Genome Project, check out www.ornl.gov/hgmis/project/about.html.

"Thar She Blows." "Potential for Large-scale Submarine Slope Failure and Tsunami Generation Along the U.S. Mid-Atlantic Coast," Neal W. Driscoll et al., *Geology,* May 2000. "Overpressure and Fluid Flow in the New Jersey Continental Slope: Implications for Slope Failure and Cold Seeps," Brandon Dugan and Peter B. Flemings, *Science,* July 14, 2000.

"Straight Talk." "Perceptual Assessment of Intoxication Level," Harry Hollien, Rebecca Hill, and Camilo Martin, The 139th Meeting of the Acoustical Society of America, Atlanta, May 2000. See asa.aip.org.

"Robot Watch." "The Future Is Now—U.S. Postal Service Robots," presented by John C. Weller at the Robotics Industries Association's Robots and Vision Show in Detroit, May 11-13, 1999; for proceedings, see www.robotics.org.

"Armageddon in a Can." For fusion fun and factoids, see the National Ignition Facility site at lasers.llnl.gov/nif.html.

"Next, the Copier Will Reproduce Popsicles." For a detailed explanation of the process, see www.umr.edu/~vrpl/rfp.htm.

"Ask the Wizard." The Voice Center at Eastern Virginia Medical School has a site devoted to the human voice: www.voice-center.com.

"They Invented It When?" For more, see *Ancient Inventions,* Peter James and Nick Thorpe, Ballantine Books, October 1995.

28 FUTURE TECH
For more about computing with leeches, see www.physics.gatech.edu/chaos.

34 THE PHYSICS OF . . . FOUL SHOTS
Peter Brancazio's *SportScience: Physical Laws and Optimum Performance,* Simon & Schuster, 1985, and *What Makes a Boomerang Come Back: The Science of Sports,* Sharon Blanding and John J. Monteleone, Longmeadow Press, 1992.

An excellent page on optimizing your basketball shots: www.phys.washington.edu/~young/208A/basketball.html.

42 WORKS IN PROGRESS
See more satellite images of icebergs at the Web site of the Antarctic Meteorology Center: uwamrc.ssec.wisc.edu/amrc/amrcgallery.html.

46 SKY LIGHTS
For more about planetary exploration, see nssdc.gsfc.nasa.gov/planetary/chronology.html.

50 TWENTY WAYS THE WORLD COULD END
Robot: Mere Machine to Transcendent Mind, Hans Moravec, Oxford University Press, 1998.

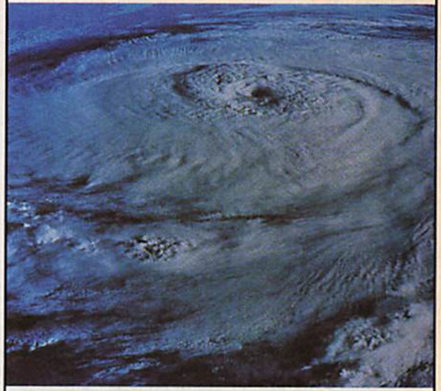
The End of the World: The Science and Ethics of Human Extinction, John Leslie, Routledge, 1996.

The folks at the Bulletin of Atomic Scientists maintain the famed "Doomsday Clock" at www.bullatomsci.org/clock.html.

58 WHAT YOU'LL NEED TO KNOW
For more information about key people and topics discussed in the article, see Jaron Lanier's Web site at www.well.com/user/jaron, the National Human Genome Research Institute at www.nhgri.nih.gov, and the Whitehead Institute for Genomic Research at www-genome.wi.mit.edu.

62 TWENTY SPECIES THAT WE MIGHT LOSE
The Biodiversity Crisis: Losing What Counts, edited by Michael J. Novacek, American Museum of Natural History, 2000. A collection of essays devoted to perspectives on species extinction and possible solutions.

Precious Heritage: The Status of Biodiversity in the United States, edited by Bruce A. Stein, Lynn S. Kutner, and Jonathan S. Adams,



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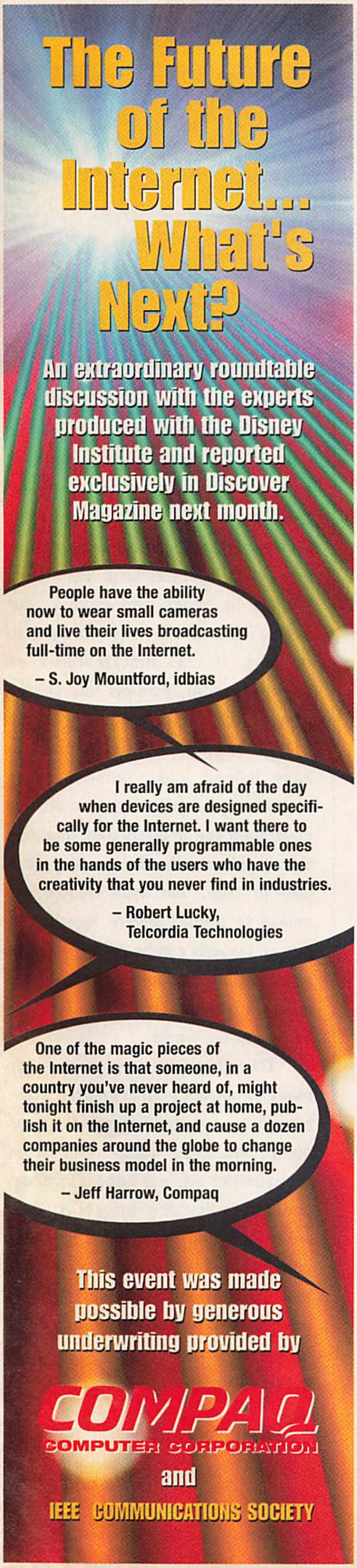

The Future of the Internet... What's Next?

An extraordinary roundtable discussion with the experts produced with the Disney Institute and reported exclusively in Discover Magazine next month.

People have the ability now to wear small cameras and live their lives broadcasting full-time on the Internet.
– S. Joy Mountford, idbias

I really am afraid of the day when devices are designed specifically for the Internet. I want there to be some generally programmable ones in the hands of the users who have the creativity that you never find in industries.
– Robert Lucky, Telcordia Technologies

One of the magic pieces of the Internet is that someone, in a country you've never heard of, might tonight finish up a project at home, publish it on the Internet, and cause a dozen companies around the globe to change their business model in the morning.
– Jeff Harrow, Compaq

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Oxford University Press, 2000. A lavishly illustrated look at what we're losing and where.

We thank the International Center for Gibbon Studies (ICGS) for its help with this article. ICGS is a nonprofit organization devoted to the study, preservation, and propagation of highly endangered gibbons: www.gibboncenter.org.

78 THE TWENTY GREATEST BLUNDERS

To find out what to do if you took fen-phen, see www.fda.gov/cder/news/feninfo.htm.

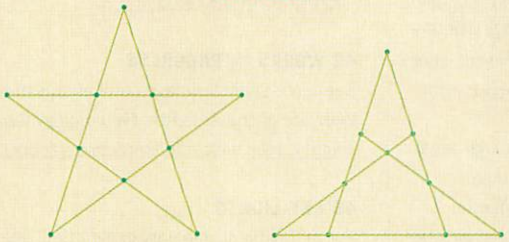
Invasive species bugging you? See a report by the U.S. Geological Survey's Biological Resources Division at biology.usgs.gov/s+t/SNT/noframe/ns112.htm.

For further information on the Chernobyl disaster, visit the Uranium Institute at www.uilondon.org/chernidx.htm.

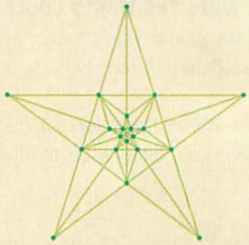
The official NASA site dedicated to the Challenger disaster is www.hq.nasa.gov/office/pao/History/sts51l.html.

BOGGLERS SOLUTIONS

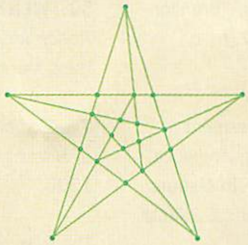
20 TREES



1. The 10 trees form a five-pointed star. For one of many other solutions (right), draw five lines that overlap one another in a different way.



2. This solution uses three nested five-pointed stars.



3. One solution uses two nested five-pointed stars at different angles.

20 QUESTIONS

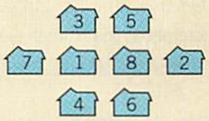
1. Your first question should be "Is your number greater than 500,000?" Based on the answer to that question, keep asking questions that divide the remaining range of possible answers in half. For instance, the next question will be either "Is your number greater than 250,000?" or "Is your number greater than 750,000?" depending on whether the answer to the first question is no or yes. Each question doubles your chances of guessing the right number, and 2^{20} is 1,048,576—more than enough chances to deduce any number from 1 to 1,000,000.

2. As in the previous solution, you should ask questions that help limit the range of possible answers. For example, your first question should be: "Is the number (a) less than 333,333; (b) between 333,334 and 666,666; or (c) between 666,667 and 1,000,000?" Each successive multiple-choice question you ask triples your chances of getting the answer. Thirteen questions are needed, because the first power of 3 that is at least as large as 1,000,000 is 3^{13}, which is 1,594,323.

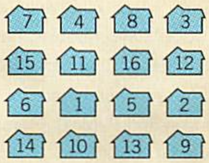
3. 27 is indistinguishable from 9 and 81. 20 is indistinguishable from 100. Four is indistinguishable from 92. 97 is indistinguishable from prime numbers greater than 23, and 93 is indistinguishable from 87 and 69.

4. The deducible numbers up to 100 are: 6, 8, 11, 12, 13, 17, 19, 21, 22, 24, 26, 28, 30, 33, 34, 35, 36, 38, 39, 40, 42, 44, 45, 51, 52, 55, 56, 57, 60, 63, 65, 66, 68, 70, 72, 76, 77, 78, 80, 84, 85, 88, 90, 95, 99.

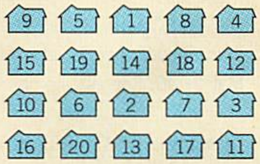
20 PAINTED HOUSES



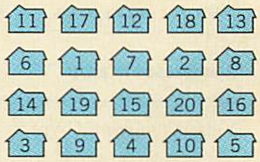
1. This solution is unique, ignoring mere reflections.



2. This puzzle has many other solutions.



3. This puzzle has many other solutions.



4. This solution requires a one-day wait after house number 18.

HOW MANY 20s?

The numeral 20 appears 20 times on page 106, as follows:
5 times in 20/20 Visions (introductory text).
4 times in 20 Painted Houses
6 times in 20 Questions
4 times in 20 Trees
and 1 time in "October 2000"

84 TWENTY THINGS THAT WILL BE OBSOLETE

The Web site of the Institute for Human Gene Therapy at the University of Pennsylvania is www.med.upenn.edu/ihgt/index.html.

For more information on the state of the world's petroleum supply, see the U.S. Geological Survey's World Petroleum Assessment Report: greenwood.cr.usgs.gov/energy/WorldEnergy/DDS-60.

We thank Darrow's Fun Antiques, 1101 First Avenue, New York, NY 10021 (212-838-0730), for providing props, and the Wiz, 17 Union Square West, New York, NY 10016, for lending the Sony television set used in our photo shoot.

92 TWENTY THINGS THAT WON'T CHANGE

Henry Petroski's *The Pencil: A History of Design and Circumstance,* Knopf, 1992, and *The Evolution of Useful Things,* Vintage, 1994, offer perceptive looks at technological change.

The Foundation for the Future is a nonprofit organization "dedicated to increasing and diffusing knowledge concerning the long-term future of humanity." Check out its Web site: www.futurefoundation.org.

Robert A. Heinlein's science fiction classic *The Door Into Summer,* Ballantine Books, 1993 (reprint edition), offers up a vision of the year 2000 you won't recognize.

99 REVIEWS

For more about Zahi Hawass and his work, surf to guardians.net/hawass/index.htm. For details of the Manchester Mummy Project, see www.museum.man.ac.uk/collections/egyptology/egyptology_research.html.

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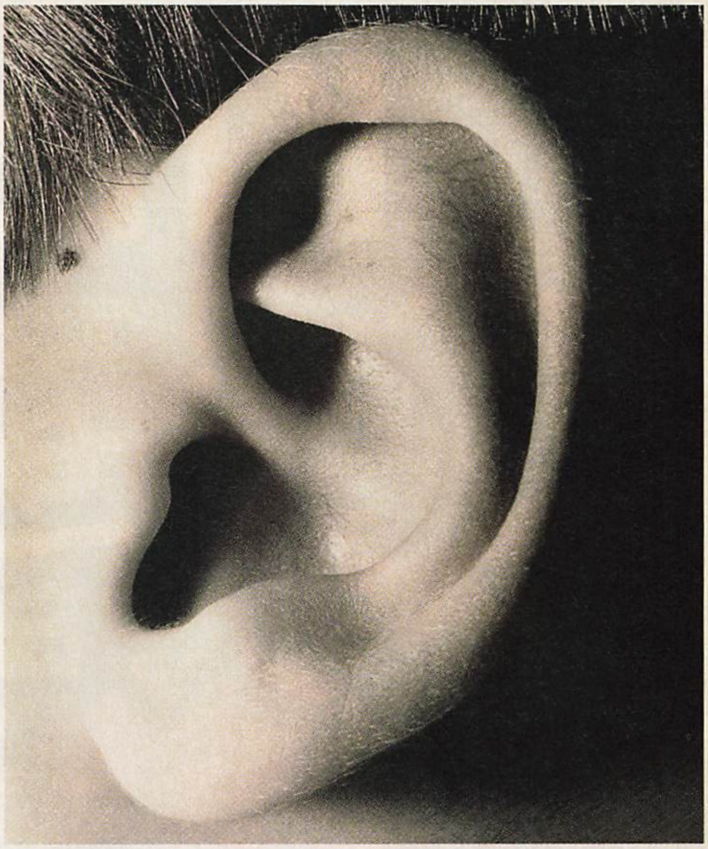
Quiet, Please!

How come your brain can filter out every sound except the voice of the sexy stranger in the corner?

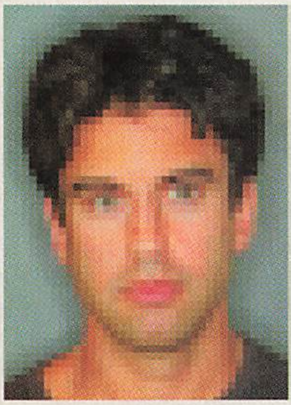
BY ERIC HASELTINE

WE SWIM IN A TURBULENT SEA OF NOISE—horns honking, boom boxes blaring, birds chirping, fans whirring, kids playing, hammers hammering, neighbors yammering—but aren't normally aware of it because our brains do such a marvelous job of sifting out sensory flotsam and jetsam.

This filtering comes in very handy, because the secret to gathering meaningful data about the world, whether it's information coming in through our ears, eyes, fingers, or taste buds, is discriminating between useful sensory signals and bothersome junk. Try these three experiments to see how effective your own brain is in increasing your signal-to-noise ratio.



EXPERIMENT 1 While you're reading this text, your brain selectively filters out distracting sounds. To find out how good a job it is doing, turn out the lights, pick out just one of the sounds that you had tuned out, and zero in on it to the exclusion of everything else. You might discover, for example, that a clock doesn't just go *tick*—it goes *ker-chuck-click*. Such a heightened auditory sensation results from your brain's reclassifying what it previously detected as noise to a worthwhile signal. Psychologists call this the cocktail-party phenomenon, after our uncanny ability to pick out a single voice in a room polluted with many voices and understand what that voice is saying.



EXPERIMENT 2 Squint your eyes and study this digitally sampled image. The picture should actually look better when you squint because the smearing of sharp edges that results removes noise added in the digitizing process—without significantly affecting the brightness and color variations that carry relevant information. Thus, by eliminating more noise than signal, you improve the signal-to-noise ratio.

EXPERIMENT 3 Although we often decide which types of sensory information are useful and which kinds are noise, sometimes we don't get to choose. This is especially true when the noise comes from inside our own brains instead of the outside world. Turn the lights out again and cover your eyes. Wait about 20 seconds for any afterimages to fade, then observe the constellation of white points and blobs that seems glued to the backs of your eyelids. These luminous images, called phosphenes, are visual noise created by random electrical discharges of nerve cells in your brain. Like the snow static on a poorly tuned TV, phosphenes carry no useful information. However, they are so weak they only cause trouble when you're trying to detect extremely faint visual signals, such as dim stars in the night sky. Go outside on a clear, moonless night and check it out. ☒

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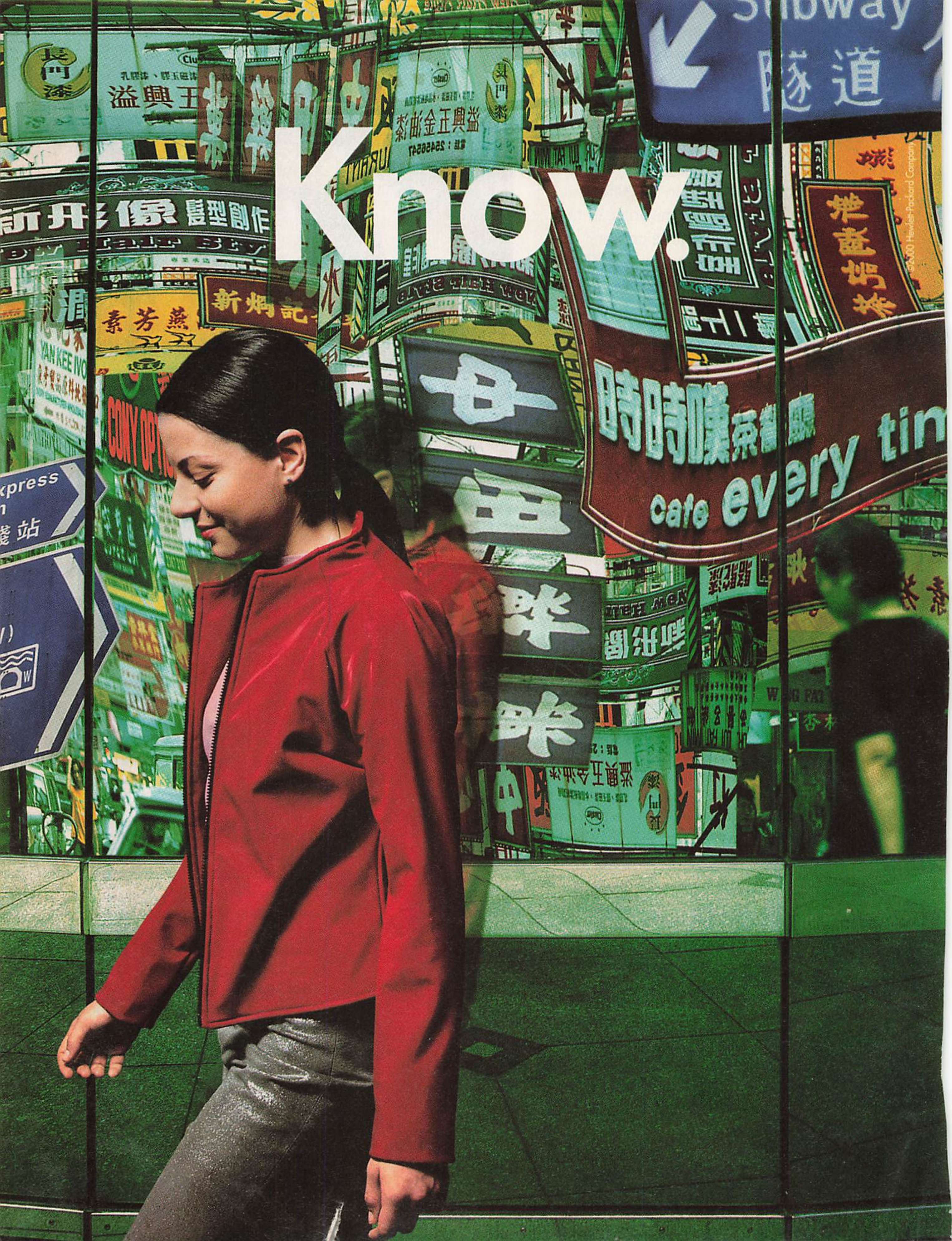
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